DESIGN OF A GENERIC SUSTAINABLE HOUSE

Alberta
MUNICIPAL AFFAIRS
Innovative Housing Grants Program

[redacted]

DESIGN OF A GENERIC SUSTAINABLE HOUSE

November 1991

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A.C.E. Alternative and Conservation Energies Inc.

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FOREWORD

The project documented in this report received funding under the Innovative Housing Grants Program of Alberta Municipal Affairs. The Innovative Housing Grants Program is intended to encourage and assist housing research and development which will reduce housing costs, improve the quality and performance of dwelling units and subdivisions, or increase the long term viability and competitiveness of Alberta's housing industry.

The Program offers assistance to builders, developers, consulting firms, professionals, industry groups, building products manufacturers, municipal governments, educational institutions, non-profit groups and individuals. At this time, priority areas for investigation include building design, construction technology, energy conservation, site and subdivision design, site servicing technology, residential building product development or improvement and information technology.

As the type of project and level of resources vary from applicant to applicant, the resulting documents are also varied. Comments and suggestions on this report are welcome. Please send comments or requests for further information to:

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Alberta Municipal Affairs
Housing Division
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16th Floor, CityCentre
10155 - 102 Street
Edmonton, Alberta
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First, we must extend a special thank you to Mr. Ian Moir for his dedication and research work on "A Photovoltaic and Grid-Connected Electrical System" for the sustainable house (see Appendix 3). We would also like to take this opportunity to thank the following individuals who volunteered their time and resources to this project - Mr. Orian Low, Mr. Bill Stollery, Mr. Emile Rocher, Mr. David Rouseau of Team Five in Vancouver, Mr. Mitchell Elliott of P.G.A. Architectural Group in Calgary, Dr. Rob Dumont of the Saskatchewan Research Council, Dr. Stanfield of the Alberta Association for Environmental Housing and Health, Dr. Natalia Krawetz of the Environment Council of Alberta, Mr. Brian Evans, MLA with the Environment Caucus Committee, Mr. Tim Mayo of Energy Mines and Resources Building Group, Mr. Steve Loken of the Center for Resourceful Building Technology in Missoula, Montana, Ms. Elizabeth White of Marsh Hill Farm, Mr. Harry Anderson of Canadian Western Natural Gas Ltd., Mr. Lewis Nakatsui of Lincolnberg Homes in Edmonton, Mr. Layton Park of Total Design Builders in Grande Prairie and Mr. Paul Belanger of Lucid Systems and Green Foundation. We would also like to thank the following individuals for their interest in our study; Ms. Sara Groves of the Municipality of Burnaby, Ms. Angela Evans of the Regional Municipality of Waterloo, Alderman Helen Rice of the City of Grande Prairie and Mr. Joseph Calenda of the South Peace Regional Planning Commission in Grande Prairie. We would like to thank the following individuals from Alberta Energy who provided valuable information for the study; Mr. Glen Lawrence, Mr. Goldie Edworthy and Mr. Calvin Karabonik. We would like to thank the following individuals from the City of Calgary who provided support and information for this study; Mr. Derrick Harrison of Waterworks Division, Mr. Des McVeigh of the Planning Department, Mr. Jim Anderson of the Land Department, Mr. Cliff Storvold of the Mayors Office and Alderman Sharon Fisk. Finally we would like to thank the Alberta Municipal Affairs Housing, Research and Development Department for the financial support through the "Innovative Housing Grants Program"and their management commitment that made this study possible. A special thank you is to be extended to Mr. Terry Toth of Alberta Municipal Affairs Housing Division whose support and commitment was greatly appreciated by the authors.

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At the time of this report the authors are pursuing several demonstration possibilities and opportunities. Interested readers are encouraged to contact them at;

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EXECUTIVE SUMMARY

Sustainable development refers to the use and treatment of the environment and its raw materials and resources in a manner which will not affect the ability of future generations to do the same. Concern over the state and preservation of the environment has fast become a matter of high priority for governments at all levels, industry, trade and professional associations, and the public in general. Using the principles of environmental protection and recognizing that affordability must also be preserved to promote marketability, this project encompassed the detailed design of an affordable sustainable house.

Specific project objectives included:

1. the identification of environmentally responsible features and techniques that can be incorporated into the design of a single detached dwelling in a cost-effective manner with no adverse effect on the saleability of the house in the mainstream urban market;

2. the production of detailed working drawings; and

3. validation of the cost of the resultant sustainable house.

Through personal expertise, the assessment of information gathered from existing literature, and consultation and interviews with industry representatives, the project team developed a set of environmental performance criteria, which could be used to quantify the performance of the house to be designed against that of a similarly sized conventional house. These criteria include quantity of lumber used, electricity and water consumption, heating/cooling requirements, generation of pollutants, and overall energy impact.

In the preliminary stages of design, a comprehensive and all-encompassing list of environmentally beneficial features was compiled. This list was closely examined in terms of marketability of the various features. Those deemed detrimental in terms of salability to the urban consumer were discarded. Surviving elements were subjected to cost examination. The benchmark for this examination was the 3-bedroom 4-level split house used by Alberta Municipal Affairs in its annual House Cost Comparison Study. As required, the list of environmentally beneficial features was further culled, by discarding items in the order of least preference, to maintain unit cost compatibility with the benchmark house. Remaining items were then incorporated into the detailed working design of a generic sustainable house.

The resultant drawings and specifications were then submitted to three Calgary builders for detailed pricing and to the City of Calgary for confirmation of compliance with municipal requirements. As necessary, further refinements concerning price and physical form were carried out.

The final design of the sustainable house features slab-on-grade construction, exposed (patterned) concrete floors in some areas, an airtight, energy-efficient envelope, high performance glazing, a livable attic, a waste recycling and composting center connected to the kitchen, an integral solarium (greenhouse), passive solar-assisted domestic water and radiant floor heating, mechanical ventilation, grey water recovery and re-use, rainwater collection, energy-efficient lighting and optimum daylighting, and specific-purpose photovoltaics, to name but a few. Special efforts were expended to ensure that non-toxic or very low toxicity materials were specified throughout. The compact 3-bedroom design contains 1175 square feet on the main floor and a fully developed attic area of 375 square feet, for a total of 1550 square feet of living space. Drawings A2 and A3 depict the layout of the home.

The house will require 20 percent less lumber to build than would a similarly sized conventional house. Calculations indicate that electrical and water consumption can be as much as much as 72 percent and 67 percent (respectively) less than that of a conventional household. Natural gas consumption is estimated to be 79 percent lower than conventional space and hot water heating requirements. Researchers were not able to put comparative figures to the pollutant generation and overall (embodied) energy impact criteria of the house because of the lack of existing and available data in these categories. The design philosophy, however, placed great emphasis on minimization in these regards.

Based on submitted quotations, the purchase price (excluding lot) of the sustainable house is estimated as **$68.80** per square foot in 1990 dollars. This compares favorably with the purchase price of the benchmark house, **$65.53** per square foot. The incremental cost of $3.27 per square foot can be recouped in five to ten years through utility savings.

The project demonstrated that the principles of environmental responsibility can be cost-effectively applied to housing in a manner that does not detract from the marketability of the house and minimizes lifestyle adjustments. Benefits can accrue to all involved, including material manufacturers, builders and consumers. Most importantly, investment in sustainable housing constitutes investment in the preservation of the environment.

At the time of this report, the authors are exploring proposed and potential demonstration opportunities.

1.0) INTRODUCTION

The concept of sustainability refers to the judicious use of the environment and its resources in a manner that will not impair the ability of future generations to do the same. A standard dictionary defines sustainability as "keeping in existence, maintaining, and prolonging". In 1989, the Environmental Council of Canada defined sustainable development as "the management of resources in such a way that we can fulfill our economic, social, cultural and aesthetic needs while maintaining essential ecological processes, biological diversities and naturally occurring life support systems. However it is defined, the goal of sustainability - preservation of the environment - remains the same.

Society is becoming increasingly aware of, and interested in, environmental preservation principles such as reducing, reusing and recycling materials. These principles can be successfully and effectively applied to the housing industry. The conventional house is designed and constructed by means and methods that often result in unnecessary waste of both materials and energy. The purpose of this project was to combine the principle of sustainability with the techniques and technologies of architecture and building science in the design of a generic sustainable house which will demonstrate the importance of, and the options available for, addressing global environmental concerns and opportunities, and which will also demonstrate the significant contribution that can be made by the housing industry to the preservation of the environment.

Throughout the project, it was realized that design alone without the potential for, or the probability of, transfer to the marketplace, would be meaningless. The sustainable house must be recognized as a marketable product by house builders and as an affordable and desirable home by consumers. Marketability and affordability were therefore included as important, and occasionally limiting, factors of the project.

1.1) Focus and Objectives of the Work

The work of the project focused on a single-detached dwelling of new construction. Several objectives were pursued enroute to the final design. These were:

- identification of various physical parameters which can be used as comparative yardsticks in measuring the performance of the sustainable house, and which also provide directional guidance for research and design efforts;

- identification of sustainable features and techniques that can be incorporated into the design of an otherwise conventional tract house in a cost-effective manner with no adverse effect on the saleability of the house in the mainstream urban market;

- design development, with prediction of performance in terms of the comparative yardsticks, and with identification and demonstration of various methods and opportunities for integrating innovative technologies, progressive construction practices and natural materials;

- validation of the cost of the sustainable house, and

- production of detailed working drawings of the sustainable house sited on a typical urban residential lot.

1.2) Study Approach

For many years, the firm has concentrated on environmentally responsible design. The expertise developed during that time was largely responsible for the identification of the performance gauging

parameters. This was enhanced by a detailed review of existing literature and precedents in Canada, the United States and Europe. Market trends and preferences were established primarily through analysis of a detailed questionnaire which was completed by builders, professionals, relevant government agencies and various other representatives of the housing industry.

Design features evolved as a combination of the best fit to performance criteria, and the best response to market preference within the scope of affordability.

Affordability was established in terms of the average (1990) cost of a single family house as determined by the annual House Cost Comparison Study undertaken by Alberta Municipal Affairs. Where periodic review showed that the limits of affordability were being exceeded, the design was modified by elimination of the least preferred (in terms of marketability) sustainable feature(s).

1.3) Report Structure

The report is organized in the following manner;

- Section 2.0 discusses the literature review, the industry questionnaire and the market trends revealed by the study;
- Section 3.0 describes the various precedents analyzed;
- Section 4.0 describes the selection and quantification of the performance-gauging parameters and the selection of design features for the sustainable house;
- Section 5.0 presents the design drawings and specifications for the sustainable house (Note: the report contains generalized drawings only. Detailed working drawings have also been prepared and can be obtained at nominal cost from the authors);
- Section 6.0 details the expected performance of the sustainable house in terms of the parameters noted in Section 4.0;

- Section 7.0 reviews the cost and the comparative cost-effectiveness of the sustainable house, and
- Section 8.0 presents the conclusions and recommendations of the project.

2.0) DATA COLLECTION

The purpose of this work was to analyze and synthesize both published and collected information relating to sustainability as it applies to housing construction and operation.

2.1) Literature Search

Key topics established as terms of reference for the literature search included energy efficiency, conservation, waste management, climate conscious design and construction, solar energy, natural and recycled materials, indoor air quality, outgassing levels, embodied energy and environmental quality. A wealth of information was found pertaining to elements of sustainability in general; however, a very limited amount of literature devoted specifically to sustainable housing was found.

The most informative literature found was a series of papers written by the Worldwatch Institute, addressing concerns for problems of the future. All of the papers primarily focus on energy conservation and the use of viable alternative energy sources. Two of them, Worldwatch Paper 23 and Worldwatch Paper 48, are based on the attainment of a 'Sustainable Society'. The September 1978 Worldwatch Paper number 23, titled 'Repair, Reuse, Recycling - First Steps Toward a Sustainable Society', by Denis Hayes, outlines various proposals for construction and basic household material waste reduction. The March 1982 Worldwatch Paper number 48, titled 'Six Steps to a Sustainable Society', by Lester R. Brown and Pamela Shaw, outlines ways and means of preventing further environmental deterioration. Essentially, both papers propose that the elimination of unnecessary materials is better than simply recycling them. Further, waste reduction saves materials, reduces energy demands, eases environmental problems, and eliminates some of the clutter in contemporary life. These concepts are noted as the terms by which a 'sustainable development' can ultimately be achieved. These concepts also helped to establish the principles for this study.

The answer to the question of 'what would a sustainable house look like?', is that the house would be simple and that "material well-being would almost certainly be indexed by the quality of the existing inventory of goods, rather than by the rate of physical turnover. Planned obsolescence would be eliminated. Excessive consumption and waste would become causes for embarrassment, rather than symbols of prestige". (Hayes, #23, 1978) This quote is intended to illustrate that our present society is driven by economics and prestige. Contrarily, a 'sustainable house' is a symbol of simplicity and comfort. It is not intended to compromise lifestyles; rather it must be viewed as a rethinking of the way we have been building housing. In the literature, education is cited as a primary method of informing the public about 'sustainable housing'. This could be accomplished in many different ways (workshops) but the most effective method is through the provision of an actual product that can be viewed, reviewed and accepted or criticized.

The 'shelter' is a necessity of life in all cultures and it comes in many varied shapes, sizes and styles. But such a necessity in North America is purchased at an unnecessarily extravagant energy cost. Buildings consume energy through different methods in four phases. "First, energy is used to manufacture materials for construction, such as the energy required to cultivate and process lumber products. Second, additional energy is used directly in the construction process such as in the actual assembly process. Third, the final product, the house, requires daily energy throughout the building's lifetime, and fourth, for many structures, a last burst of energy is needed for the building's demolition". (Hayes, #4, 1976). Such "embodied energy" (total amount of energy used) information is not readily available to the public and especially to new home purchasers. The literature that is available shows the importance of energy-efficient appliances, insulation, and viable alternative energy sources, but there is a definite lack of a collective source of materials that can inform the consumer about the features and benefits of sustainable housing. Such information would allow home buyers to make conscientious decisions to ensure that their home is constructed and maintained in the most energy-efficient and environmentally responsible manner.

From a review of various publications it was discovered that builders and developers have already planned and built complete communities in suburban areas in Los Angeles, Phoenix and Colorado that have applied environmental considerations in every home. For instance a 24 unit subdivision in Phoenix was built using rammed earth methods (walls made of clay, gravel and sand), integrated passive solar heating and cooling, and photovoltaics. Many single family homes in the southwestern United States are presently being constructed using these concepts. The problem with these projects is that they tend to be localized and are only exploited in specialized publications that are not readily available to the general public.

The Home and Community Design Branch of Alberta Agriculture published a book in 1987 titled "Low Energy Home Designs". It consists of design guidelines and plans for energy-efficient housing. In addition it has a section on "Housing Trends-What the Future Holds". The following is a summary of the main points taken from the book;

- Trends in housing must reflect a knowledge of our environment and a desire to control the costs of energy use.
- The "single-family" home will not dominate the housing market.
- The rising cost of energy will influence mortgage financing of future housing.
- Operating the home will become more important.
- Window design will play an important role in successful low energy home design. The ability to capture, control and use heat from these solar collectors will have to be incorporated into low energy homes if one expects to lower energy costs.
- The rising cost of housing is resulting in design for longevity in terms of structure and finishes.

- The cost of building is also leading to a reduction in the total area of the average home. Open plans and multi-function spaces will become prevalent.
- Reduction in plan size has also increased the importance of properly designed storage space.
- The high cost of housing is resulting in a new wave of "do-it-yourself" builders.

These guidelines are intended to illustrate some elements that must be taken into consideration in order to achieve sustainability. The two most important components are energy efficiency and cost effectiveness. However, these are only expectations presented by a government agency and as long as they are not enforced or demanded by the consumer they may never progress to rules from desires. It must become the responsibility of the housing industry as a whole to promote these expectations so that they do not remain merely as desires.

2.2) Industry Questionnaire

A questionnaire was formulated in order to determine if an overall awareness of sustainable development principles exists, if there is the potential acceptance of housing oriented towards sustainable development, and to basically identify the related needs, requirements and interests of the housing industry. The questionnaire was distributed to various groups, agencies and individuals that are stakeholders in the housing industry. A sample of the questionnaire is included in the report as Appendix 1. The following are conclusions and interpretations that were derived from the questionnaires by the authors.

The most common concerns respecting a sustainable house concept related to marketability, economics and practicality. Each respondent made general reference to the fact that there is no perceptible demand for sustainable housing by the public at this time, but the same public will demand and buy environmentally friendly products at a premium.

The majority of respondents agreed that a viable starting point in the promotion of sustainable development is energy conservation. It is seen as the most tangible and practical form of an environmental strategy that is both accepted by industry and in increasing demand by the public.

Most respondents tended to agree that it must become the responsibility of the housing industry to educate consumers about environmental housing and to offer choices. The respondents believed that public interest in environmental housing would grow with continued education and availability of environmentally sensitive choices.

Also included in the questionnaire were questions on design features, which are discussed in Section 5.

2.3) Market Trends

Journalists, realtors, builders and suppliers were interviewed in order to obtain information on local marketing trends. There was a general consensus that there exists a concern for energy-efficiency, not in terms of conservation but rather in terms of cost savings. Insulation is generally identified by the consumer as the main component in making a home energy-efficient. The primary benefit to the consumer is a reduction in ongoing energy costs. The consumer is generally unaware of the energy and environmental costs involved in the construction of a house.

Many builders are installing energy-efficient furnaces and appliances into homes. These items are "features" that are considered extras. Double and triple-glazing, skylights, radiant floor heating and solariums are luxuries that are placed in larger or more expensive homes. These items are not generally marketed as energy conservation features; rather, they are viewed as means of saving money on heating bills. Such "luxuries"as they are presently regarded, should become standard features in all housing in order to contribute to a sustainable future.

The following list is a compilation of features which, in the opinions of those interviewed, represent "future typical components" that may be found in homes that promote sustainability both in terms of energy efficiency and energy conservation (many of these features have also been identified in various literature sources):

- smaller houses
- open plans
- low maintenance materials
- improved concrete - mixture of portland cement & recycled plastics, fibers
- water conservation
- low-flush toilets that use rainwater
- recycled building materials
- recycling centre
- elimination of wall-to-wall carpeting
- hardwood floors
- passive solar heating
- radiant floor heating
- high performance windows & doors
- air-to-air heat exchangers
- photovoltaics for electricity
- fluorescent lighting - task lighting
- energy-efficient & cordless appliances
- landscaped gardens
- pre-fabricated housing
- smart houses - integrated automation

These items will be expanded upon in Section 5 of this study.

These items are not regarded as innovative nor are they difficult to install in homes built by tract builders. However, the existing housing market has, to date, not encouraged the placement of the majority of these items into conventional homes. This is partly because certain items are not cost-effective due to a lack of demand (ie. photovoltaics). However, as consumers change into conservers, these items will become typical features rather than luxuries or options.

From the interviews, a general conclusion most commonly acknowledged as being a major problem was that the industry in Alberta has always had easy access to inexpensive energy resources. Conservation, therefore, has not been a priority. It was recognized that these resources are depleting and they will in the future become expensive commodities with significant environmental repercussions. The housing industry in Alberta, and in the rest of Canada, will have to respond to the resultant problems and opportunities.

The most tangible and widely accepted aspect of environmental housing is energy-efficiency. Most often, reference was made in the various interviews to the R-2000 program, as being the best example of energy-efficient housing. The R-2000 home was developed in the late 1970's by the Federal Department of Energy, Mines, and Resources and the Canadian Home Builders Association, in response to escalating energy costs. The R-2000 home is a super energy-efficient house that offers greater comfort for its occupants and costs substantially less to heat than a conventional home.

The R-2000 home is constructed with stringent energy-efficient standards. Each home uses a heat recovery ventilator, energy-efficient doors, low-E windows, higher levels of insulation and an airtight envelope. Most of these features are not typically used in the housing industry as standard features. As a result, a conventional home that is built to the minimum standards of the building code will lose much of its heat through air leakage and comparatively low insulation levels. The R-2000 home can reduce the loss of warm air to the outside by 40 percent. It allows less noise penetration from the

outside, better control of the interior environment, greater comfort and higher resale value. The natural reaction therefore is, why are these homes not being built and made available? In Alberta very few R-2000 homes are built. A few members of the housing industry have indicated that builders became uninterested in building a product that would typically cost 10 to 15 percent more than conventional houses, but, more importantly, realtors were unwilling to promote and sell the R-2000 home. The reason for their unwillingness in the past is that consumers in Alberta were transient, short term home owners with little concern for the future, long-term benefits of an R-2000 home. However, recent trends towards energy conservation have initiated a renewed interest in the concept of R-2000. In order to succeed it must address the issue of cost effectiveness. This can be achieved by integrating the best features of the R-2000 home (ie. airtightness) and adding solar energy features with innovative cost saving construction methods (for example, 610mm on center framing) and the result could be an affordable, cost effective and energy efficient house.

Those interviewed reiterated that change can occur through education, a principle widely accepted as being a possible solution for the promotion of sustainability. In their opinion, educational workshops are a valuable means of informing the public about energy and materials used to build a house. The house building industry in Alberta does not presently provide such workshops to the public. However, workshops in environmental housing do exist in other parts of Canada, especially in Nova Scotia. Workshops allow the general public to participate in the building industry. The workshops inform the participants about the methods and means of constructing an energy-efficient house. As a result, the participant will employ or will require that those materials and techniques be employed in the construction of their own homes. Those members of the housing industry that have been involved in educational workshops admit that the most important component is the actual field trip to completed projects. Walking through a built project is the best method of promoting energy-efficient housing.

3.0) PRECEDENTS of SUSTAINABLE BUILDINGS and PROJECTS

Many of the precedents studied utilize many aspects of sustainability, but only one of the projects (under extreme circumstances) could be regarded as 'totally sustainable'. The project is called 'Biosphere II' and is located in Arizona, U.S.A. (see 3.9). Most of the precedents are new projects and some address existing housing stock. Each example was chosen on the basis that it contains elements that made the building and the project sustainable. The desirable parameters that the homes addressed were; energy-efficiency, unique or innovative construction techniques, low fossil fuel requirements, renewable resource utilization and environmental sensitivity. These are the environmental principles that establish the basis for the design of the sustainable house.

3.1) Hamilton Solarium - Calgary

This 32.52 m^2 (350 $ft.^2$) solarium addition to the Hamilton residence was built in 1982. The integrated features of this contractor-built addition are as follows:

- passive solar heat gain
- cross-through and chimney-effect ventilation
- internal brick wall solar collector
- natural convection
- maximum daylighting
- destratification of warm air
- natural materials
- passive solar cooling
- retractable awning for shading
- thermal mass for heat storage
- radiant floor heating
- indirect fluorescent lighting
- recirculating of warm air to existing house
- hot tub

Since the completion of this project, the Hamiltons have spent much of their time in this bright, sunny and warm sunroom, in the company of their many plants. The plants also contribute to the indoor

environment of the home in that they absorb carbon dioxide while producing oxygen, humidity and negative ions.

Subsequently, this project has led to the following developments on this average city lot:

- basement renovations to promote circulation
- solar electric lighting
- rain water collection
- compost bin

In summary, after eight years of successful operation, this normal urban lot displays many simple alterations that can be accomplished economically. The solarium is not only used as a living space year round, but also as a production greenhouse in the spring to start seedlings for garden transplanting. It also illustrates many features that are environmentally sound. All features incorporated in this small project are easily within the scope of the general contractor and relevant sub-trades.

3.2) Stampede Sunseed - Calgary, Alberta

This demonstration building was constructed for the 1979 Calgary Stampede. Approximately 60,000 people toured this project to learn about, to touch and to see the following features:

- energy conservation techniques
- passive solar heating
- solar greenhouse
- solar attic collector and reflector
- passive solar cooling
- thermal mass, trombe walls
- sunscoop (clerestory)
- maximum daylighting
- insulating curtains
- waterless toilet
- air-locks
- built-in planter boxes for planting

- cross-through & chimney-effect ventilation
- roof shading
- photovoltaics
- usable & accessible roof terrace
- wind electric generator

This was one of the earliest public buildings in western Canada that demonstrated conservation of depleting resources, renewable energy supply, waste management and environmental stewardship.

3.3) Silver Willow Pheasant Farm Lodge - Carstairs, Alberta

This lodge uses old traditional design materials with a concern for present-day responsible energy use. The lodge is located on 129.5 Ha (320 acres) of land just outside the town of Carstairs, Alberta. It is a daytime lodge that caters to game hunters from all over Alberta.

The building is 83.6 m^2 (900 $ft.^2$) and is designed on an open plan concept. The plan includes a kitchenette with a serving counter, a sitting/snack area, a games corner and two washrooms. The total cost of the building was approximately $50,000.00 for labor and materials. During construction the power tools were powered with photovoltaic panels that were attached to an inverter. On occasion a generator had to be used. The integrated features of this building are as follows:

- passive solar heating
- air-tight wood burning stove (back-up)
- cellulose insulation; walls & ceilings
- generation of electricity by photovoltaics (pv) for water pump, radio, lighting, fan & small appliances
- recycling of black water
- all wood construction
- preserved wood foundation
- board and batten siding
- hard wood flooring, trim & baseboards
- re-sawn wood ceiling
- Phoenix waterless composting toilet
- grey water dry well

The project was completed in July of 1990. This project has been successful in addressing various environmental issues through the use of materials and energy sources that are not harmful to the environment. With time, the functionality and success of the systems used can be properly assessed and reviewed.

3.4) Stollery House - Devon, Alberta

This is an owner-builder project. It is an energy-efficient passive solar heated house that is located north of Devon Alberta on an acreage overlooking the North Saskatchewan river. A unique feature of this project is that it is considered an 'earth sheltered home'. The main floor on the east, west and north sides of the home is earth bermed. The earth embankment provides the advantage of shelter from extreme air temperatures and increases airtightness, which reduces requirements for heating and maintenance, as those sides of the building are not exposed to the weather.
The house also has the following features:

- a south facing solarium with a hot tub
- an air-to-air heat exchanger
- the use of greywater for flushing toilets
- passive solar heating
- a wood burning stove
- rainwater collecting cisterns

There are three south facing bedrooms on the second floor. The north side contains the dressing and bathroom areas for the master bedroom, the study and the laundry area. On the north side of the main floor are the pantry, two cisterns, the mechanical room and the rear of the garage, which is the storage and workshop area. The property in general has good solar access. Apple trees and a vegetable garden have been planted on the south side. Liquid effluent from the septic tank is used to water (and fertilize) the lawn instead of potable water. Numerous mountain ash trees and evergreens have been planted on the north side as part of the shelter belt.

3.5) Environmental Resource Centre - Edmonton, Alberta

This project is worth mentioning as an example of an existing building that has been retrofitted. It is an old brick building that has had the following features installed:

- an air-to-air heat exchanger
- blown-in cellulose insulation; added to interior and exterior walls
- the basement flooring was replaced with an insulated slab
- a set-back thermostat
- efficient gas water heater
- insulated water pipes and heater
- double-glazed awning type windows
- a root cellar

Public recycling bins (for the separation of newsprint, jars, bottles, cans and garbage), solar hot water collectors and an organic garden are all located in the Resource Centre's back yard. All features are labeled with explanations. Its major purpose is to educate the public on environmental and energy matters. These aspects demonstrate and contribute to the sustainable development of a conserver society.

3.6) Chareve Community - Rural Central Alberta

The Chareve Community is a small multi-family housing project in rural central Alberta that was built in 1987. It is one of the most sustainable buildings located in western Canada. It is a project that was built by students of a Bible School and illustrates the joys and pains of self-help construction. Its features include:

- energy conservation
- recycled greywater for irrigation

- passive solar heat gain
- party walls to reduce heat loss
- radiant floor heating
- maximum daylighting
- waterless toilets
- straw-bales for some insulation
- live-in attic space
- most wood for structural members, cupboards and finishing was recycled from an old grain elevator, school & store
- low maintenance & low embodied energy materials
- partially built into side of a hill

Future plans have been made to add a major passive solar greenhouse addition to the southside of a warehouse located on the property. The Chareve Community backyard is full of recycled and reusable materials. Several of the nearby buildings in the community were entirely constructed out of recycled materials. One such building is insulated entirely with straw-bales. Photovoltaic panels have been purchased to operate several small electrical appliances. There is an ongoing process of improvement and change in this project. This continuity of growth is an important sustainable principle.

In summary, this project is a radical departure from conventional construction, and is outside the scope of the normal housing industry, but nevertheless it has many useful lessons to share. It certainly illustrates a far less detrimental impact on our natural surroundings than conventional construction.

3.7) Ecology House - Toronto, Ontario

This is a retrofitted, three storey, 90 year old brick building in downtown Toronto. It demonstrates the possibility of conversion of past liabilities into present assets for our common future. It has been Canada's best known working demonstration of urban ecology. Pollution Probe, EMR Canada and the

Ontario Ministry of Energy, and many representatives from industry, participated in the planning and construction of this important landmark building.

Amongst its many laudable features the visitor will find:

- energy conservation
- retrofitting techniques
- solar domestic hot water system
- composting toilet
- greywater recirculating
- energy-efficient appliances
- organic garden
- water saving devices
- thermal mass (heat storage)
- insulating shutters & curtains
- exterior insulation
- passive solar heat gain via 'trombe wall' & natural convection
- solar greenhouse addition & retrofit

Through the use of energy conservation, passive and active solar heating, waste management and community involvement, this successful education centre continues to illustrate a great assortment of environmentally sound features that make it, in all probability, the most sustainable upgraded house in Canada.

3.8) Northwood Estates, Bridgewater - Nova Scotia

Northwood Estates in Bridgewater Nova Scotia is a subdivision that promotes energy-efficient solar homes. The homes in the subdivision were built by Mr. D. Roscoe, a designer and builder of energy efficient housing. Mr. Roscoe formulated the following list of rules that he applies to all the homes:

1. Stack living spaces in multi-levels on the south side of the house.
2. Locate utility areas on the single-storey earth-bermed north face.

3. Extend a saltbox roof from grade level on the north to the two-storey south elevation.
4. Design the exterior in a manner that will create naturally protected outdoor courtyards.
5. Open the interior south core to the second-floor ceiling to create an indoor courtyard, overlooked by balconies and interior windows.
6. Omit the basement; build on a monolithic slab foundation that doubles as thermal storage, absorbing heat from the sun and from warm-air ducts buried in the concrete. Heat radiates passively back into the room.
7. Install a thermal break between the heat-storage slab under the house and the concrete under unheated spaces.
8. Locate a fan above the two-storey indoor courtyard to push warm air toward the furnace intake.
9. Use an electric furnace to circulate sun or stove-heated air through the slab and to provide backup heat.
10. Install chimneys inside the thermal envelope of the house.

These rules maintain consistency in all of the homes. Omission of the basement and placement of the heating system in the slab are the most important. In Mr. Roscoe's opinion, the basement is a costly and unnecessary part of conventional homes. He believes that the home should be placed in the environment with minimal disruption to its site. Excavation is an expenditure of energy that disrupts the environment and results in a space that requires additional energy to produce and to maintain. Warm air heating ducts that would normally be placed in the basement of a home are placed in an eight inch concrete slab. The heating system then operates similar to a radiant floor heating system.

3.9) Biosphere II - Tucson Arizona, U.S.A.

The worlds largest experiment on sustainability is being conducted near Tucson, Arizona. A group of scientists are now living in this totally sealed, self-sustaining, 0.81 Ha (2 acre), thirty-million dollar

glass domed mini-earth replica. This 165 meter (540 foot) long 'biosphere', built with private venture capital on Sunspace Ranch, is an exercise in how to "scale down planetary processes and keep them going". It is based on the premise that "global processes on a small scale can be contained and maintained by humans in a symbiotic relationship for mutual survival". Its commercial purpose is to gain expertise for the colonization of space. The only external resources are sunlight and air. Some of the other features of this huge passive solar terrarium include:

- a desert, savanna, ocean, rainforest, marsh
- domestic & wild animal areas
- biological & mechanical filtering systems
- desalination units
- supplemental rain sprinklers
- composting toilets
- agricultural wing
- waste management & recycling
- computer controls & monitoring

Shopping malls, leisure centers and retractable roofed stadiums are smaller analogies to domed mini-worlds. While these serve the commercial aspects of our consumer society, the project described here is meant "to improve man's stewardship of earth."(N.R.C., 1981) With financial backing, scientific management and encapsulated segregation from earthly dynamics, this project is the most sustainable building known to the authors at this time. It is, however, an extreme example of sustainability, especially in terms of cost.

3.10) Integral Urban House - California U.S.A.

This house has been the urban centre of the Farallones Institute since 1974. During the first year, a staff of ecologists and builders transformed a dilapidated old dwelling into a self-reliant urban habitat. It is devoted to the study and demonstration of environmentally-sound methods of on-site food production, energy and water conservation, waste recycling and solar energy, suitable for

application in urban areas. This retrofitted old house is, in all probability, the best known United States example of sustainable living using existing housing stock. It is the American equivalent to Toronto's "Ecology House".

Amongst its many applications are the following features:

- solar space heating & water systems
- waterless biological toilet
- greywater recycling system
- urban farm techniques, roof-top garden
- savonius wind rotor
- composting systems
- environmental landscaping
- energy conservation
- solar greenhouse

This project illustrates to city dwellers the scope of opportunities for integrating many aspects of sustainability into the average existing lot and building.

3.11) Meadow Creek - Arkansas, U.S.A.

This rural community in Arkansas was developed in the 1980's for the purpose of education and research into applied ecology, agriculture, renewable energy systems, forestry, wildlife, and demonstration of the ethical, social, economic and political aspects of sustainability. This project exemplifies the principles of sustainability in action. Some of the most progressive environmental design and ecological planning in North America has taken place here. The approach is very holistic.

By 1987, five homes, two dormitories and a large conference centre had been constructed, with the following features:

- energy conservation techniques
- passive solar heating
- active solar hot water heating
- radiant floor heating
- photovoltaics
- composting toilets
- party walls
- wind energy
- sweat-equity construction

3.12) Solar I Subdivision - Phoenix, U.S.A.

'Solar I' is perhaps the largest suburban scale development that has achieved a good degree of sustainability. It was built by the largest builder in Phoenix, in the mid 1980's. This community comprises 24 single family homes with the following features:

- traditional design & aesthetics
- rammed earth construction
- high levels of insulation
- radiant barrier in the roof
- solar hot water heating
- hybrid cooling system
- off-peak electric use
- thermal mass & storage
- low operating costs
- large community photovoltaic system integrated into the area power grid
- energy management controls

The authors believe this precedent to be one of the most interesting, innovative and environmentally-sound housing projects for contemporary society in North America, built by a large tract builder.

3.13) Centre for Alternative Technology - Wales, U.K.

In the 1970's, a group of concerned citizens in Wales wanted to demonstrate environmental responsibility through action. An abandoned slate quarry was converted into a visitor and educational centre of international reputation. 'Alternative Technology' is technology that is: "sustainable, fair, interdependent, non-destructive, pollution-free, cyclic and economical". About thirty staff members operate the centre, which has approximately 55,000 visitors annually. A live-in type community is featured. Some of the demonstrations now operating include:

- photovoltaic systems
- wind energy systems
- battery storage
- composting toilets & sewage
- recycling bank - heat reclamation
- solar walls & roof, hot water collectors
- water turbines and wheels
- greywater heat exchanger
- low energy self-build houses
- energy conserving construction

Monitoring, experimentation, comparative testing, tours and consulting services are continued at the site on a full-time basis. The site is not connected to the utility grid. Most of the power is derived from renewable resources. They "try and show that a good, comfortable lifestyle can be achieved using far less electrical or other power than the usual norm."(N.R.C., 1981)

3.14) The Dutch Policy on Global Warming - Precedent of Government Action;

The Dutch government has published a 'National Environmental Policy Plan' (NEPP) that is a long-term plan from 1990 to 2010 and is based on the principle of sustainable development. It is a policy that is targeted towards the the reduction of CO_2 emissions by 80 percent and the reduction of CFC emissions by 75-100 percent This is in response to the concerns over global warming and is an attempt to protect

the stratospheric ozone. The following list was presented to the Standing Committee on Environment, House of Commons, Ottawa' (Halloquist, 1978), by Dr. Metz, Councilor for Health and Environment, Royal Netherlands Embassy;

- tightening of building code standards (insulation)
- regulation of efficiency standards (boilers for residential heating, washing machines, dryers, fans, refrigerators, freezers)
- subsidies for energy conservation programs (insulation of residential buildings, installation of heat pumps, industrial conservation projects)
- public information and education programs, involving public utilities
- fuel switching for electricity generation from coal to natural gas
- subsidy and tax break programs for renewable energy generation (solar, wind) co-generation and other high efficiency generation methods
- matching funds for research and development
- provision of energy consulting services to industry

The Dutch government has been vigorously pursuing an international convention on global warming. It is their belief that the problem can only be addressed effectively through international co-operation. The Dutch government has initiated a study of a sustainable building. "The idea is to look at all aspects of building, from the raw materials to the actual usage and the location, etc., and try to come up with an integrated approach to a more environmentally friendly type of living... It is one of the activities we undertake to try to achieve fundamental changes in the way we produce, in the way we consume, in the way we move ourselves, etcetera."(Brutland, 1987). The sustainable building project was initiated in early 1990. This is an example of a country that is not taking its future for granted. Instead it is attempting to implement policies that will guarantee a clean and secure future for its citizens.

3.15) Summary

A total of thirteen precedents were studied. They are examples of the growing number of houses and buildings incorporating aspects of sustainability, but very few of those buildings are fully committed to wholesale integration. All of the buildings address energy-efficiency, promote conservation and are environmentally sensitive to a degree, however, with the exception of a few, most are not truly sustainable. Many of the projects are not self-sufficient. They were constructed with materials that are not truly sustainable and they still contain conventional back-up fossil fuel systems. They are all, however, examples of a genuine effort, contributing to the pursuit of a sustainable future. In relative terms, such precedents are but a fraction of all new housing, but they are functioning models and living lessons that clearly point the way to reducing environmental degradation and extolling the virtues and returns of sustainable development. It is partly from these precedents that the operating parameters and design criteria for the sustainable house were derived.

4.0) RESIDENTIAL CONSTRUCTION and POST-OCCUPANCY WASTE

An environmentally responsible design process must, in addition to supporting ways and means of reduced consumption, promote the minimization of incompatible waste material returned to the environment, in both the construction-related and post-occupancy periods.

4.1) Residential Construction Waste

A report titled, "Making a Molehill Out of a Mountain" was commissioned by the Toronto Home Builders Association. The report examines the scope of the landfill crisis within the greater Toronto area, the state of waste management amongst renovators and new home builders, and presents alternatives to sending construction and demolition wastes to landfills.

The figures in the report were established with builders' estimates of their own site observations in the greater Toronto area. The author assumes that these estimates can be applicable in general, to the housing industry across Canada. The assumption is based on the use of similar construction techniques, materials and types of buildings. Table 1 provides an average percent figure for each category of waste;

Table 1 - Material Wastage

Waste Category	% Total Waste
Dimensional Lumber	25.0
Drywall	15.0
Masonry & Tile	12.0
Manufactured Wood	10.0
Corrugated Cardboard	10.0
Asphalt (shingles, roofing paper etc.)	6.0

Waste Category	% Total Waste
Fiberglass	5.0
Metal Wastes	4.0
Plastic and Foam	4.0
Other Packaging	4.0
Other Waste	5.0

It is difficult to translate the percentages into quantities relative to the finished product. The study attempts to quantify the percentages by weight. For instance, dimensional lumber and manufactured wood products make-up 35 percent of all the waste and this equates to 0.845 tonnes (0.93 tons) per house. This is equivalent to 200 two-by-four studs or 10 percent of all the lumber purchased for the house. In essence, if the waste produced in the construction of ten houses was accumulated, one could build an entire house. Such waste of materials not only reduces natural resources but more importantly it accelerates the deterioration of the environment.

There are different forms of waste that are produced at various stages of construction. They range from material neglect to the spilling of paints and other toxic materials. The introduction of the garbage container for instance, had a direct impact on landfills. That is, it made waste removal convenient. As a result, contractors are unaware of the actual amount of material that is discarded. Each time a full garbage bin of waste is removed from a construction site, a contractor and landfill site have to be paid, in turn these costs are passed on to the consumer.

4.2) Post-Occupancy Waste

Canadians are the largest per capita energy consumers in the world. In 1988, the average citizen in Canada used an equivalent of 44 barrels of oil, in comparison to a citizen in Japan who only used 18 barrels of oil. Canadians are also seen as the most wasteful people on earth according to Environment

Canada. On average, each person in Canada throws away four pounds of household garbage per day, of which nearly 50 percent is packaging. This is difficult to recycle, and is placed in landfills or is burned, which in turn releases toxic materials into the air or soil. The average household is also seen as the major generator of hazardous waste. An estimated 35.23 litres (7.75 gallons) of toxic material which comes in the form of household cleaners, disinfectants, drain openers, paints and polishes are disposed of annually by each household to landfill sites or into sewage systems. This in turn poisons the water that people drink, and the soils that grow our food.

4.3) Dealing With Waste

The total elimination of wastage of building materials would be difficult. One possible solution would be pre-manufacturing the entire building. However, human error is a factor that must be taken into account, and relocating the source of waste does not guarantee its reduction or elimination.

From Table 1 it should be noted that 45 percent of the waste originates from trees. Yet trees are much more useful to society as live carbon dioxide absorbers, than as dead waste. Wood and cardboard can certainly be recycled into the soil as fertilizer. Mineral by-products constitute another 27 percent of waste. Gypsum and masonry scraps can easily be stored on site and placed in wall cavities to increase the buildings thermal mass or as an aggregate component in the concrete slab. This would result in a saving of time, effort and costs to the builder, home buyer, and municipal landfill site, and would help conserve our natural environment. There are other factors that must be taken into consideration when wasted materials end up in landfills. Certain materials contain toxic chemicals that emit vapors and gases into the atmosphere and into the soil. These toxic substances may end up in the air we breathe, the food we eat, and in the water we drink.

To assist with the design and subsequent evaluation of the sustainable house, various performance - oriented criteria were selected. Waste reduction played an integral role in the selection of these parameters, and in the design features that were derived from them. The following section describes these criteria.

5.0). SELECTION and QUANTIFICATION of PERFORMANCE CRITERIA

A house can be described in terms of basic elements that apply to its construction and its day-to-day operation during occupancy. For the sustainable house designed within the scope of this project, it was considered important that such a set of elements be derived to aid in the subsequent identification and selection of design features, and to assist in comparing the predicted performance of the sustainable house to that of a similarly priced conventional house. For the purposes of this project, these elements (referred to as performance criteria) were identified as:

- the quantity of lumber used,
- electrical energy consumption,
- water consumption,
- heating/cooling energy consumption,
- indoor environment characteristics, and
- embodied energy impact.

The following subsections discuss each of these performance criteria in detail, beginning with a discussion of the conventional house in terms of the particular criterion, followed by a description of the resultant environmental impact. Then a list of design features, intended to minimize adverse environmental impact, is presented in each subsection. It should be noted that some of the design features itemized could apply to more than one performance criterion.

An extensive comparative inventory chart is included as Appendix 4. It outlines all of the features that were considered and either accepted or rejected based on considerations of practicality, marketability, cost-effectiveness, durability, local manufacture, availability, indoor air quality,

environmental impact, conservation, recyclability, embodied energy, simplicity, low maintenance, use of renewable resources, energy consumption and carbon dioxide emissions.

5.1 Lumber

The typical Canadian home averages "1240 square feet (115 sq. m.) and requires a total of 9000 board feet (2743 m) of lumber [7500 board feet (2286 m) for framing and 1500 board feet (457.2 m) for non-framing]. On average, an Alberta tree produces approximately 75 board feet of lumber"(Kennedy, 1989). The average Alberta house, therefore, will require the use of 170-215 trees. As noted in section 4.1, approximately 10% (the equivalent of 17 to 22 trees) of the lumber required for a house is waste material. Trees harvested for housing cannot help in the reduction of carbon dioxide. Trees are an essential part of the carbon sink. A single mature tree absorbs 5.90 kilograms (13 pounds) of carbon dioxide per year and a younger actively growing tree absorbs 11.80 kilograms (26 pounds) of carbon dioxide per year. If 215 trees are used in building a house and each tree absorbs, on average 8.85 kilograms (19.5 pounds) of carbon dioxide, each new house diminishes carbon dioxide absorption by 1900 kilograms (2.09 tons) each year.

In this project, some wood products were re-evaluated in terms of sustainability and environmental friendliness. Particleboard for instance, is most commonly used for exterior sheathing, interior cupboards and counters. It is manufactured with the use of formaldehyde, a chemical that causes various types of irritations, provokes allergies and may cause bronchial asthma. This is one material that could be eliminated and replaced with solid wood materials that have little environmental and health impact.

In general, lumber is a product that can be replaced through programs that promote reforestation. However, adherence to basic environmental principles suggests that the amount of lumber actually

required to construct a house be minimized. One method of minimizing waste is through thoughtful design based on dimensions that reflect dimensional lumber sizing.

The "Sustainable House" will contain the following features that relate to 'Lumber'. The environmental principles incorporated in the selection of these features were reduction of waste and energy, use of technology that promotes recycled products, and alternative construction techniques.

Framing System

The framing system that is typically used is based on 410mm (16") spacing. By employing a 610mm (2'-0") spacing, framing material could be reduced by approximately twenty percent which means less trees harvested and less energy required to cultivate and process them, and potential cost savings for the consumer.

Floor Joists

Wood-I beams, made primarily from recycled wood, tend to be stronger and more flexible in application than 38x184mm (2x8) or 38x235mm (2x10) solid lumber joists. Wood-I's can span greater lengths than conventional joists. The cost for a 9 1/2" wood I is similar to 38x235mm (2x10) joist.

Roof Rafters

Roof rafters require less cutting and wasting of lumber than roof trusses. There would be less energy used and less carbon dioxide emitted from the burning of fossil fuels needed to produce the energy required for manufacturing. Rafters are used for cathedral ceilings, a popular marketing feature. They allow the funnelling of stratified warm air to specific locations from which areas it can easily be collected for recirculating. The use of rafters allows for open, usable and habitable attics. Trusses are typically spaced on a 610mm (2'-0") spacing system and

rafters can be similarly spaced. In addition, they can be designed to align with the wall studs below.

Diagonal Bracing

Standard particleboard sheathing need not be used solely to achieve racking strength on walls. There are more economic and environmentally responsible techniques that can be used such as wood 25x100 mm (1x4 inch) diagonal let-ins.

Roof and Wall Sheathing

In place of conventional roof and wall sheathing materials the sustainable house will incorporate wood shingles on 25x100mm (1x4) slats for the roof and EPS Type 2 rigid insulation covered with stucco for the walls. Substantial savings resulting from the decreased use of lumber, and from reductions in material waste and labour costs can be realized. In addition, there will be a savings in manufacturing energy consumption and a resultant reduction in carbon dioxide emissions. Conventional floor sheathing can be replaced as much as possible, with scrap materials that are free of harmful binders that may outgas into the house.

Wood Waste Reduction

The reduction of construction material waste, especially wood and drywall can be achieved by minimizing or eliminating on-site cutting of materials. The design and construction of the sustainable house is to be based on dimensional wood sizes. The interior walls are to be 38x64mm (2x3)stud. Drywall scraps can be transformed from a liability into an asset by storing them in interior cavities to enhance thermal inertia (heat storage).

5.2 Electricity

Electricity is very often taken for granted. Table 2 compares a 'typical modern house' in Canada with an R-2000 house on an annual basis: (Kennedy, 1989)

Table 2 - Electrical Use Comparison

House	Consumption GJ	kWh	Average Price	Total Cost
Typical	50-100	14,000-28,000	5.5c/kWh	$770-$1,540
R-2000	20 - 30	5,600 - 8,400	5.5c/kWh	$310- $460
SAVINGS	30 - 70	8,400-19,600		$460-$1,080

Note: 5.5c/kWh is based on a Calgary utility rate.

The R-2000 house takes into account energy-efficient appliances and lighting systems. For instance, an 18 watt fluorescent fixture emits the same amount of light as a 75 watt incandescent fixture and lasts 13 times longer. Lighting is responsible for about 20 percent of Canada's electrical output. A conventional middle income Calgarian home uses 8,600 kilowatt hours per year versus 4,100 kilowatt hours per year for an energy-efficient house. According to statistics from the City of Calgary Electric Department, an average household of 1000 square feet with four occupants in Calgary, consumes 750 kilowatt hours monthly, or 9000 kilowatt hours annually. The following is a comparison of all types of energy required annually in homes of various construction types (kilowatt hours per year): Advanced House: 11,000 ; R-2000 : 24,000 ; Alberta Building Code House : 36,000 (White, 1989).

A variety of methods are available to produce electricity directly from the sun, including wind, solar thermal (ie. steam), and photovoltaics Although solar generated electricity has seen a dramatic price

reduction in recent years, it is still relatively expensive. It is however, in the author's opinion, worth paying some economic premium for a source of electricity that is safe, dependable, renewable, automatic, non-controversial, non-polluting, and in the case of photovoltaics, highly decentralized. Of all of the emerging renewable power technologies, photovoltaics is perceived by most utilities as having by far the greatest potential. The advantages of photovoltaics are no moving parts, quiet operation, non-reliance on non-renewable energy sources, elimination of air pollution and a high degree of modularity. Appendix 3 of the report is an indepth study of "A Photovoltaic and Grid-Connected Electrical System for the Sustainable House" that was prepared by an electrical engineer.

The "Sustainable House" will contain the following features that relate to 'Electricity'. The environmental principles incorporated in the selection of these features were use of a natural resource (sun), use of technology that minimizes the use of coal generated electricity, reduction of carbon dioxide emissions and control of electromagnetic pollution.

Maximum Daylighting
The house design will take full advantage of natural lighting and minimize the number of lighting fixtures required.

Energy Efficient Lighting
The use of open area plans will reduce the number of fixtures required. Task lighting will also minimize wastage of electrical energy.

Indirect Fluorescent Lighting
Fluorescent lighting is much more efficient than incandescent lighting. A 40 watt fluorescent tube will produce twice the amount of light as a 100 watt incandescent bulb. Fluorescent tubes will also last up to 13 times longer than incandescent bulbs. Full spectrum lighting is by far the

most healthy form of artificial lighting. Reduced wattage fluorescents can further reduce electric consumption by 13 to 20 percent as compared to standard fluorescent fixtures. Folded fluorescents are also available for incandescent sockets. They have twice the efficiency and eight times the life of an incandescent bulb. Fluorescent light fixtures will be used in the kitchen and bathrooms.

Quartz Halogen Lights

Halogen bulbs stay bright and last much longer (2,000 to 3,000 hours) than incandescent bulbs. The filament also burns hotter, so halogen bulbs emit a whiter light with truer color rendition. The halogens will be used in certain lamps in the bathrooms, living room, bedrooms and hallways.

Photovoltaics - Solar Electric Panels

Photovoltaic (PV) panels are solar electric modules, composed of many semi-conductors called solar cells. The solar cells are manufactured from silicon (sand). Their efficiency varies from about nine percent for amorphous panels to 11 to 13 percent for mono-crystalline modules. These modules provide a clean and simple way of converting sunlight directly into electricity. An electric current is created through the photovoltaic process when light hits solar cells. PV systems do not require complex machinery, engines, or heat-conversion methods, and they operate silently. Present costs of electricity from PV in the United States are about five times higher (at $0.25-$0.35 kW/h) than conventional generating stations (at $0.06 kW/h).

When photons (energy particles of daylight or sunlight) strike solar cells, electrons are knocked out of orbit. A P-N (positive-negative) barrier (a one-way diode) prevents these electrons from filling the hole created, thus forcing them to flow along the only path possible through a load, back to the solar cell in an effort to fill the holes left behind, thus creating an electric current. PV modules range in power output from 1.5 to 55 watts. The electrical panel will be integrated

in parallel (to increase current) or series (to increase voltage). Many modules compose an array. The main components of a PV system are the modules, voltage regulator, battery storage and the load. The sustainable house will have 10 photovoltaic panels (500Wp) that will store energy in five 110 amp batteries. This element is questionable in terms of initial cost effectiveness, however, it can be justified in terms of environmental benefits. See Appendix 3 for a detailed report on photovoltaics (see drawing A-3 for photovoltaic schematic diagram). Further cost-related discussion of photovoltaics is contained in section 8.2 and 8.3 of this report.

Energy Efficient Appliances

Appliances use approximately 78 percent of the total amount of electricity in a home. An energy efficient appliance is constructed to operate with minimum electricity. However, the energy efficiency of the appliance depends upon the manner in which it is used and maintained. All of the appliances in the home will meet or exceed the energuide standards of energy efficiency.

The "energuide label", introduced by Consumer and Corporate Affairs Canada, indicates the number of kilowatt hours the appliance typically uses in a month when tested in accordance with CSA standards. By multiplying this figure with the utility rate one can figure out the average cost to operate the appliance. This highly successful program that now applies to refrigerators, freezers, ranges, dishwashers and clothes washers/dryers, allows customers to choose energy-efficient appliances according to energy performance. All of the appliances in the sustainable house will have energuide labels for reference and monitoring purposes.

Energy-Efficient Refrigerator

The most energy-efficient (17 cubic foot) refrigerator manufactured in North America today uses about 200 kWh per year versus 900 to 1500 kWh per year for standard refrigerators. This twelve volt DC refrigerator uses two loops, one for the freezer and the other for the refrigerator.

Several other manufacturers are now considering splitting the system into two separate sets of compressors and condensors located outside of the appliance. The refrigerator that is to be used in the sustainable house is the 16 cubic foot Photocomm P16 that uses approximately 800 watt hours per day. This power can be handled with three to five solar panels.

Sealed Combustion Gas Range

The sustainable house will have a self venting gas stove. This particular model will not produce electromagnetic pollution, nitrogen oxide or water vapor. In general it will not add to the indoor air pollution as it is a sealed combustion unit. The use of natural gas will be further discussed in section 7.4.

DC Appliances

The increasing market for recreational vehicles has accelerated the availability of DC/AC appliances. Most AC appliances are actually DC with transformers to reduce voltage and rectifiers to convert AC to DC. DC appliances now available include blenders, vacuum cleaners, pumps, T.V., radio, tools, washing machines, video equipment, microwaves, lighting, refrigerators and hair dryers. An attempt will be made to include some of these appliances in the sustainable house.

Microwave

Microwaves use electromagnetic energy. The energy is absorbed by the food rather than the air, the oven walls or containers. The use of a microwave will reduce energy consumption due to shorter cooking time. Their average power consumption is 1.45 kilowatts.

5.3 Water

Water consumption is a difficult resource to monitor accurately. Each household varies in size and requirements, but above all else, the attitudes of each household will vary. The following is a typical household water budget, based on a four person household in Calgary, that was compiled by the waterworks department of the City of Calgary;

Table 3 - Household Water Consumption

Use per person per month:				**Cubic Meters**
Toilet	90 x	@	23 litres per flush	2.07
Shower (5 min.)	30 x	@	75 litres 5 min.	2.25
Faucet (minutes)	30 x	@	25 litres per minute	0.75
			Total per person	5.07
Household use per month:				
Dishwasher	60 x	@	64 litres per load	3.84
Clothes Washer	16 x	@	230 litres per load	3.68
Faucet (minutes)	110 x	@	25 litres per minute	2.75
Household use per month:				
Leaking Faucet	5 x	@	25 litres per day	0.13
			Total per home	10.40
4 PERSON HOUSEHOLD		=	30.68 CUBIC METERS PER MONTH	
		OR	368.16 CUBIC METERS PER YEAR	
Household Irrigation:				
Lawn Sprinkler	950 litres per hr x 5 hrs per week x 12 weeks per year			
TOTAL ANNUAL IRRIGATION			57.00 CUBIC METERS (1000 litres)	
TOTAL ANNUAL DEMAND			**425.16 CUBIC METERS (1000 litres)**	

Table 4 summarizes the average monthly demand for water by a family of four.

Table 4 - Average Monthly Demand (4 person household)

Toilet	99.36 m^3	20.5%
Shower (5 min.)	108.00 m^3	22.2%
Faucet (minutes)	36.00 m^3	7.4%
Dishwasher	46.08 m^3	12.7%
Clothes Washer	44.16 m^3	12.1%
Faucet (minutes)	33.00 m^3	9.1%
Leaking Faucet	1.50 m^3	0.4%
Lawn Sprinkler	57.00 m^3	15.6%
TOTAL:	**425.16 m^3**	**100.0 %**

These estimates represent average water consumption for a conscientious household. It is estimated that such households equal approximately 10 percent of all water consumers. It is very difficult to cross reference different cities in terms of water consumption due to many varying factors such as leakage of water and different climatic conditions, but mainly due to variations in consumer demands.

It should be noted that the per capita consumption of water in Calgary is double that of Edmonton. The main reason identified for this is that most Calgary homes are on a flat water rate whereas homes in Edmonton are metered. Flat unmetered water rates encourage water waste since residents pay the same amount no matter how much water is consumed.

Water is a non renewable and precious resource that is taken for granted. For instance, on a per capita basis, Canadians use an average of 5000 litres of water per day(much higher than the average residential demand); the British use 840 litres per capita per day and the Swiss only use 350 litres per

capita per day (Note: Totals include water usage by industry). It requires energy (coal and natural gas in Alberta) to pump, treat, deliver and heat domestic water.

The "Sustainable House" will contain the following features that relate to 'Water Conservation'. The environmental principles incorporated in the selection of these features were the use of technology that minimizes the consumption of water, use of a natural resource (rain), and the recycling of greywater;

Low Flush Toilet

A low flush toilet is one which uses 1/2 to 14 litres (1 pint to 3 gallons) of water per flush in comparison with 23 to 27 litres (5 to 6 gallons) of water used by conventional toilets. The sustainable house will use domestic water in combination with rainwater that is collected in a 680 litre cistern to flush the toilet as a means of water conservation for a four to six month period. The low flush toilet that will be used in the sustainable house is a cottage toilet that uses 1 pint of water to flush. This equates to the use of approximately 90 pints (11.25 gallons) or 51 litres of water per person per month based on 90 flushes.

Low Flow Shower Heads

Low flow shower heads consume 8-11 litres per minute (1.8-2.5 gallons per minute) compared to 22-36 litres per minute (5-8 gallons per minute) consumed by regular shower heads. This represents a potential saving of about 60-70 percent. Such devices simply restrict the volume of water internally and increase pressure by adding air. They are cost-effective and readily available.

A hand held shower head can further reduce water usage because a person can aim the water directly to where it is required and control its flow by an on-off button which reduces both the quantity of water required and the time needed to shower.

Grey Water Recycling

Grey water recycling is the reuse of water that has been collected from baths, laundry and sinks. This water will be piped to cisterns for storage and used to water the lawn. In some cases it has been used to flush toilets. In these instances, biodegradable detergents would have to be used by the occupants.

Rainwater Collectors

Rainwater will be collected in a cistern and used for watering plants and flushing toilets (as described above). This can be achieved by directing the roof run off from eavestroughs and downspouts into appropriate containers (680 liter cistern and 205 liter rain barrels). In certain cases, potable water can be obtained in this manner through a proper filtering system..

Water Meter

A water meter will monitor the amount of water that is used per household. This will allow for a more responsible and lower water use. Studies have shown that installing water meters in homes, even without rate increases, permanently reduces water use between 10 and 40 percent. The lower the water consumption, the lower the costs for both water supply and sewage treatment. Water meters are presently a requirement of many communities; the City of Calgary, however, does not presently require them.

5.4 Heating and Cooling

Heating systems in conventional houses built in Alberta typically use forced air natural gas fired furnaces. Although natural gas is abundant in Alberta, it is a finite resource. It is better than other fossil fuels (ie. coal) environmentally, but it still produces CO_2 which, as a greenhouse gas is partially responsible for climatic warming. The figures in Table 5 were taken from a pamphlet that indicates the approximate annual consumption of various gas appliances used by a typical family of four in a 1500 square foot house in Calgary;

Table 5 - Annual Natural Gas Appliance Consumption

Furnace = 135 GJ	Water Heater = 40 GJ	Range = 4.2 GJ	Clothes dryer = 4.3 GJ

The total annual consumption is **183.5 GJ Gas** (50,960 kWh - not typical for all homes), of which 175 GJ (48,600 kWh) is used for space and water heating. A home burning **183.5 GJ** of gas would produce **9.1 tonnes** (10.0 tons) of carbon dioxide annually.

Carbon dioxide is a greenhouse gas: a gas that traps solar heat and prevents it from being lost to space. "The earth's atmosphere contains greenhouse gases; in fact without these gases, earth would be too cold to be habitable by humans" (Challice, 1989). The problem however is that greater quantities of the gases are being emitted into the atmosphere through fuel burning and chemical industrial processes. According to Dr. Harvey Buckmaster, a professor of physics at the University of Calgary, the home is a major producer of carbon dioxide through heating and cooling systems. Table 6 compares the home to cars and to the human in terms of "carbon dioxide average annual emission"; (Yokel, 1980);

Table 6 - Carbon Dioxide Average Annual Emission

HOME:	175 GJ Gas for heating	= 8.8 T CO_2 (9.7 tons)	CAR:	2414 Litres Gas	= 55 T CO_2 (60.6 tons)
	171 GJ for Cooling	= 8.6 T CO_2 (9.5 tons)	HUMAN:	Respiration	= 0.2 T CO_2 (0.22 tons)

Average reductions in natural gas usage were recorded in four past projects of A.C.E.-Alternative and Conservation Energies Inc. Proportional carbon dioxide reductions were then projected to 10,000 similar homes; as a result, it was initially estimated that about 60,000 tonnes (66,100 tons) of carbon dioxide could be eliminated annually. At the same time 1,200,000 GJ of natural gas would be saved for other purposes. This can be achieved through the use of cost-effective conservation techniques in combination with passive solar space heating. These calculations were derived without any consideration to further reductions that may be achieved through lower electrical consumption, lower embodied energy in building materials, reduced water use, or CO_2 mitigation by means of judicious landscaping acting as a carbon sink.

The "Sustainable House" will contain the following features that relate to 'Heating and Cooling'. The environmental principles incorporated in the selection of these features were use of a natural resource (solar), the use of technology that minimizes the use of energy, and recycling of greywater;

Passive Solar Heating and Cooling

This type of solar energy collection, storage and redistribution is simple in concept and use, has few moving parts, and requires little or no maintenance or energy apart from embodied energy used in the solar heat sink (ie. concrete slab). The main advantages of this system are that it minimizes the need for complicated mechanical equipment and the unnecessary production of environmental pollution. Since it requires little fossil fuel input, few physical by-products or waste are produced. In addition, solar energy is conveniently distributed to all parts of the world, thus reducing or eliminating environmentally damaging transportation systems and distribution networks with their attendant power losses, health effects and maintenance costs. Solar energy is an independently produced, site generated, individually priced and decentralized energy system; fossil fuels on the other hand have inherently been dependent on a potentially

vulnerable centralized system. This system (solar energy) however must be supplemented with a natural gas-fired hot water boiler system used for the radiant floor heating.

Greenhouse

A properly located greenhouse can function as an integrated direct-gain solar heating system by generating, storing and distributing passive solar heat for use in the rest of the house. The glass traps radiant heat inside this space.

The sustainable house will include a greenhouse that will optimize and direct useful daylighting into the building. This reduces the need for coal-generated electricity for artificial lighting. In addition, the greenhouse will promote the growth of living plants which in turn will produce oxygen for fresh air and humidity for arid climates, while absorbing carbon dioxide (CO_2).

Often these spaces function as multi-purpose rooms, capable of expanding adjacent living quarters. The greenhouse can become a marketable feature of the sustainable house.

Large South Facing Windows

Windows in the sustainable house will be oriented to capture maximum positive sunlight for heating between the hours of 9:00 AM and 3:00 PM in the winter, while minimizing unwanted summer heat gain. To optimize fossil fuel reduction, south and south-east glazing areas will be much larger than any other areas. This consideration must be balanced with heat-loss, cost and privacy. Specific glazing details are discussed in section 5.6, "High Performance Windows".

Interior Mass

Common building materials can be used to absorb, store and distribute passive solar energy. Thermal mass must be integrated with all south facing glazing and with the greenhouse area. The

concrete slab (see section 5.7) will act as the largest heat sink component. The slab will absorb sunlight during the day and distribute it to the space by radiation during the evening.

Natural / Hybrid Cooling

Natural cooling, without the use of mechanical equipment can be accomplished with the dynamics of cross-through (horizontal) ventilation generated by wind, or by chimney-effect (vertical) ventilation generated by natural convection.

Passive cooling can also be accomplished through the use of outside shading (ie. deciduous trees), inside shading (ie. reflective blinds), thermal mass (to absorb excess heat for night-time elimination), air-tightness (to reduce warm air infiltration) and high insulation levels (to reduce heat conduction through the building envelope).

Sometimes natural cooling needs to be optimized or assisted by minimal use of mechanical equipment and non-renewable energy, to increase efficiency or performance. A large reversible ceiling fan is thus a hybrid system utilizing both natural dynamics and limited mechanical devices for cooling purposes.

Radiant Floor Heating

The sustainable house will be heated by radiant floor heating. Radiant heating uses either water pipes or electric cables to emit heat by radiation from the floor or ceiling. Many builders are now familiar with radiant floor heating in which hot water circulates through polybutylene tubing concealed in the floor. Heat is transmitted through the pipes to the surface of the floor and then to the room by convection and radiation. Radiant heating allows equal comfort at lower air temperatures, compared to forced air systems, and produces more uniform temperatures throughout the room. In addition, people like the absence of both noise and dust which is

associated with forced air systems, thus providing a cleaner and more pleasant indoor environment. The house is usually divided into various zones which can all be monitored and controlled individually.

Air-to-Air Heat Exchanger (ATAHE)

With a radiant floor heating system and an air tight home, an air-to-air heat exchanger will be required. The ATAHE is a mechanical device that transfers the heat contained in the outgoing, warm, moist, stale exhaust air to the incoming, cold, dry, fresh air. This heat recovery ventilation (HRV) system reduces moisture and humidity in an air-tight house and provides for air movement and ventilation to all rooms as specified by minimal air change per hour requirements. Such a system is also essential for the removal of indoor air pollution resulting from the outgassing of building materials. Heat recovery efficiency of ATAHE's ranges up to 80 percent.

Bread Box Solar Water Preheater

This simple black-painted water storage tank, in-line with the domestic hot water tank, will sit behind a south facing heat mirror. It is a passive solar preheater, that does not require the sophisticated equipment of active solar heating systems. Despite a lower efficiency than flat plate solar collectors, the much lower cost of the bread box solar water preheater makes it the most cost-effective solar hot water pre-heater. This simple horizontal tank can be built from recycled materials and can achieve temperatures of 49 degrees centigrade (120 degrees.F.) under ideal conditions. Off-the-shelf type units are manufactured in Canada and elsewhere.

Large Ceiling Fan

Good air circulation is key to circulating heat in a passive solar house. Vertical stratification occurs when warm air collects in higher spaces, ie. ceiling or upstairs, and horizontal

stratification occurs towards the solar side of the house. A ceiling fan will be used to destratify warm air and bring it back down where it is most needed. The fan will be reversible to assist both passive solar heating and cooling. Various sizes and types are readily available. They are standard in home decor and easily marketable. A 121.92 centimeter (48 inch) diameter fan is capable of moving up to 368.12 cubic meters of air per minute (13,000 CFM).

5.5 Indoor Environment

Indoor air pollution should become a main concern to the home buying public. Outgassing of construction materials may represent a serious health hazard to people with allergies. The best strategy to rectify this problem is to utilize non-toxic or low toxicity materials and adhesives in combination with proper ventilation. In the past, exfiltration and infiltration rates were so excessive that little build up of indoor air pollutants could occur due to the natural air exchange.

Indoor air pollution affects indoor air quality in the home. This pollution originates from toxic chemicals, outgassing of building materials, electromagnetic fields and outdoor sources. Table 7 was taken from a report titled 'Indoor Pollutants' by the National Research Council, which represents the different types of pollutants that can be found in the conventional tract house.

Table 7 - Indoor Pollutants

POLLUTANT	Sources of Indoor Pollution	Possible Indoor Concentration *	Indoor/outdoor Concentration Ratio *
- Carbon Monoxide	Combustion equipment, faulty heating system.	100 ppm	>>1

POLLUTANT	Sources of Indoor Pollution	Possible Indoor Concentration *	I/O Concentration Ratio *
- Respirable Particles	Stoves, fireplaces, cooking, condensation of volatiles, aerosol sprays, resuspension, cigarettes.	100-500 ug/m3	>>1
- Organic Vapors	Combustion, solvents, resin products, pesticides, aerosol sprays	NA	>1
- Nitrogen Dioxide	Combustion, gas stoves, water heaters, dryers, cigarettes,	200-1000 ug/m3	>>1
- Sulfur Dioxide	Heating System	20 ug/m3	<1 (removal inside)
- Total Suspended Particles without Smoking	Combustion, resuspension, heating system	100 ug/m3	1
- Sulfate	Matches, gas stoves	5 ug/m3	<1 (removal inside)
- Formaldehyde	Insulation, product binders, particleboard, furniture, carpet	0.05-1.0 ppm	>1
- Radon and Progeny	Building Materials, soil, groundwater	0.1-30 pCi/liter	>>1
- Mineral & Synthetic Fibers	Products, cloth, rugs, wallboard	NA	- - -
- Carbon Dioxide	Combustion, humans, pets	3,000 ppm	>>1
- Viable Organisms	Humans, pets, rodents, insects, plants, fungi,	NA	>1

Note: *Concentrations listed are only illustrative of those reported indoors. Both higher and lower concentrations have been measured. No averaging times are given. NA = not able to list a concentration, I/O = Indoor / Outdoor, ppm = parts per million, ug/m3 = micrograms per cubic meter, pCi/liter = picoCuries per liter, (N.R.C., Indoor Pollutants, 1981)

The preceding figures may not apply to all homes. Table 7 merely indicates that high levels of these pollutants were measured in some houses and as such, it is an indicator of the types of pollutants that occupants are being exposed to daily. We may never be able to totally eliminate pollutants but one must take the necessary steps to reduce and control them. A simple solution is to use environmentally sensitive materials that are not made with the use of toxic chemicals. For instance, materials that incorporate formaldehyde should not be used. That is, aldehydes and other organic substances emanate from outgassing of urea-formaldehyde found in insulation, particleboard, plywood, and fabrics. Formaldehyde has been associated with respiratory disorders, allergies, irritations and other disorders. This indicates that we must use materials conscientiously and judiciously, while defining options and substitutes.

The National Research Council outlines five indoor pollution control strategies. They are:

I. Control by Ventilation
- a) general ventilation
- b) spot ventilation

II. Control by Source Removal
- a) material or product substitute
- b) restrictions on source use, sales, and activities by type of indoor facilities

III. Control by Source Modification
- a) change in combustion design
- b) material substitution
- c) reduction in emission rate by intervention with barriers

IV. Control by Air-Cleaning (pollutant removal)
- a) particle filtering

V. Education
- a) consumer information on products & materials
- b) public information on health, soiling,nuisance

b) gas and vapor removal
c) passive scavenging or absorption

effects, and productivity

c) resolution of legal rights and liabilities of consumer, tenant, manufacturer, etc., related to indoor air quality.

Of the five strategies the most important is education. Consumers must learn to make choices that enhance their lives and at the same time contribute to the preservation of the environment.

Table 8 represents research that is being carried out on electric and magnetic fields (EMF). TransAlta Utilities has put forward a report titled; "Electric and Magnetic Fields and Health - Research and Regulatory Developments: A Summary, February 1990". A controversy exists as to whether EMF can affect one's health. It is an inevitable form of pollution that exists throughout our environment. It is difficult to eliminate as long as we depend on electricity but it can be reduced by selecting appliances that have the lowest levels of EMF yet allow the same lifestyle to be maintained.

Table 8 - Summary of Domestic Appliance Magnetic Field Measurements

	Magnetic Field - mG Measured at Source	
Appliance Type	TransAlta (range)	Private Residence
Range	1 - 80	2.6
Refrigerator	1 - 8	n/a
Microwave Oven	3 - 40	85
Oven	1 - 8	12.5
Toaster	2 - 6	1.5
Coffee Maker	1 - 2	3.6
Juicer	n/a	420
Clothes Dryer	1 - 24	5.6
Blow Dryer	1 - 75	3.0
Electric Blanket	3 - 50	n/a

	Magnetic Field - mG Measured at Source	
Appliance Type	TransAlta (range)	Private Residence
Television	1 - 40	40
Computer	1 - 25	5.0
Shaver	50 - 300	4.4
Sewing Machine	1 - 23	38
Furnace	n/a	25

Note: n/a = not available, mG = milligauss.

There is a wide range of values representative of the various levels of magnetic fields that can exist in one's home, schools and work places. The varying levels depend on the particular appliance functions and mechanical equipment characteristics.

The "Sustainable House" will contain the following features that relate to 'Indoor Environment'. The environmental principles incorporated in the selection of these features were use of natural materials instead of synthetics, and use of technology that minimizes indoor air pollution;

Low Toxicity Materials and Finishes
Low toxicity materials and finishes will be specified for the interior and exterior of the house. Lemon oil, linseed oil and beeswax in a pure mineral oil base contain no silicon or petroleum distillates and will be specified as polishing materials for cabinetry and trim that are not painted with a water base paint.

Latex Instead of Oil Based Paints
Water base paints will be used in the sustainable house because they require less energy to produce than oil base paints. In addition, their toxicity is relatively low and their production

does not deplete a limited natural resource (petroleum). Oil based paints contain volatile organic compounds (VOC's) and hydrocarbons.

Solid Instead of Hollow Core Interior Doors

Solid interior doors are to be used in the sustainable house because they are not constructed of laminated formaldehyde-laden materials. The solid door is energy efficient and has a greater noise insulation factor.

Wood Instead of Plastic Finishing

Wood will be used instead of plastic laminates for counter tops, mouldings and trim. Wood is a natural resource that does not require extensive energy to extract, process and manufacture and it is an environmentally friendly material. Plastic laminates on the other hand are petrochemically based, outgas hydrocarbons, and are assembled with toxic adhesives. These laminates require extensive energy to produce through the burning of fossil fuels and the consequent emission of carbon dioxide into the atmosphere.

Area Rugs Instead of Wall-to-Wall Carpeting

Area rugs are to be used instead of wall-to-wall carpeting and this will conserve energy as well as non-renewable resources. Carpeting is made from synthetic materials that require extensive energy to produce. Most area rugs use natural materials (ie. wool). Area rugs have the advantage of being removable for cleaning or decor changes. They can also be hung on walls as tapestries to increase wall insulation. Wall-to-wall carpeting has suffered from increased criticism due to maintenance problems related to indoor air pollution since it is a prime collector of dust and fungi, both detrimental to people with allergies. Disintegration of the underpadding has also been a problem.

Reduced Use of Adhesives

Minimizing the use of adhesives is a difficult specification to achieve when the majority of materials presently used in the housing industry require some form of adhesive. However, it can be done. Examples are: wood flooring (nailed) versus linoleum (glued); an alternative to using tiles is to stamp the tile pattern onto a concrete floor using a stencil (see Section 5.7).

Building Outgassing Period

A curing time for building products to complete any essential outgassing and for finishes to properly dry should take place before the occupants move in. The specification for the sustainable house will require that the building be properly outgassed before occupants are allowed to move in.

5.6 Energy Impact and Conservation

A majority of all construction materials used in a house are pre-manufactured. This in turn means that energy is expended in the processing of the materials. This energy is called 'embodied energy'. As fossil fuels are burned for energy, carbon dioxide is emitted. The end result is the depletion of the world's natural resources and the worsening of the "Greenhouse Effect". A paper written by G. E. Wixson, of the Michigan Concrete Paving Association titled 'Energy Impact', begins with "a look at a life without fuel", an image of the world by the year 1997. It is a world in which fossil fuels have been depleted with no substitutes, a world with continuing wastage and a population that continues to multiply. The paper also addresses the issue of energy use in the production of construction materials. Concrete and asphalt, two products that are used for roadways are compared. The conclusion was that asphalt would require 240 percent more energy than concrete. Although both products can be used for similar applications and both products require energy to produce, concrete provides greater savings in energy consumption.

The typical consumer chooses products without realizing the long-term effects on the environment. There will always be a need for expenditure of energy in the production of materials, however, choices can be made on the bases of health, pollution, and social costs rather than solely on purchase costs. A system of comparison labeling of products can affect the way we choose products.

Table 9 represents the 'embodied energy' required to manufacture some materials used in the housing industry as stated in "Energy Consumption for the Manufacture of Materials" (Halloquist, 1978).

Table 9 - Embodied Energy Required in Manufacturing Materials

MATERIAL	kWh/ton	kWh/m3
Aluminum	32,000	85,000
Steel	10,500	82,000
Plastics	11,000	11,000
Glass	5,700	15,000
Paints	2,000	2,500
Bricks	1,200	2,200
Mineral Wool	6,000	180
Gypsum Board	1,000	800
Concrete	200	460
Sawn Timber	190	100

Note: Figures were not available for dimensional lumber and wood composites.

The World Commission on Environment & Development produced the 'Brundtland Commission Report', outlining the importance of communication between consumers and producers. It outlines various proposals and policies for the conservation of existing non-renewable resources and it makes suggestions for viable alternatives. Its major conclusion is that "a low energy path is the best way towards a sustainable future." (Brundtland, 1987) Essentially this means that nations must reduce the

amount of energy they are presently consuming yet provide essential energy services. If this can be achieved, then time will be available for nations to "formulate programs on sustainable forms of renewable energy, and so begin the transition to a safer, more sustainable energy era." (Brundtland, 1987)

The "Sustainable House" will contain the following features that relate to 'Energy Impact and Conservation'. The environmental principles incorporated in the selection of these features were reduction of energy consumption (including embodied energy) through conservation, choice of materials and technology that will promote energy efficiency and use of recycled products in appropriate applications;

Sheathing

The sustainable house will use 25x100mm (1x4) diagonal bracing let-ins for racking strength instead of sheathing. With the use of wood shingles on the roof, sheathing will not be required.

Stucco/Wood instead of Vinyl/Metal Siding

These are examples of materials used for similar applications. Wood siding, for instance, requires 4,393 BTU's of energy per cubic meter to produce whereas metal siding requires 94,596 BTU's of energy per cubic meter to produce. In addition, trees are a renewable resource whereas bauxite and fossil fuels are finite. Stucco is one product for which it is difficult to obtain or determine a measurement for embodied energy. Stucco will be used on the sustainable house as it is low in maintenance, durable and creates a relatively air-tight exterior seal around the house.

Airtight Construction

In average homes, air leakage is responsible for about one-third of the heating load. Ideally, a sustainable house should be sealed tightly with no leaks tolerated. A good air barrier stops unwanted infiltration and exfiltration, and vapor migration into wall cavities. An air barrier can be located anywhere in the wall. In the interior of the sustainable house the airtight drywall approach in combination with the use of 'Right-on' paint (a water-based product) will eliminate the need for a polyethylene vapor barrier on exterior walls and will allow for an airtight seal. On the exterior the use of stucco in combination with rigid insulation will minimize air infiltration.

Higher Levels of Insulation

The minimum thermal resistance value (RSI) as specified in the code, for insulation in wall assemblies above ground is between 2.5 and 3.7 (R15 - R20). In the sustainable house, the RSI for such assemblies will be between 5 and 9 (R30 - R50). For roof assemblies the RSI value will be between 9 and 10.8 (R50-R60) instead of the present RSI value of 5.9 (R34). There are various types of insulation that can be used but the one chosen for the sustainable house is dry-sprayed cellulose (98 percent dry). Cellulose is an insulation fiber material made of shredded paper that is chemically treated to be fire and moisture-resistant. Cellulose has about 30 percent more insulation value than rock wool for the same installed thickness. Due to its greater density it displays a greater airtightness quality. In addition, it is a recycled product.

Expanded Polystyrene

Expanded polystyrene is a lightweight material that comes in a variety of thicknesses and is permeable to vapor flow. It will be used to sheath and insulate the exterior face of the walls and it will be used below grade under the slab. In addition, it will be placed 610mm (24") below grade horizontally around the perimeter of the house to protect the slab from frost. It has an RSI value of 0.026/mm (R3.76/inch).

Insulated Exterior Doors

Insulated doors will reduce heat loss - an important component in maintaining a highly sealed and airtight envelope. Polyurethane or polystyrene is usually used for insulation, with an RSI value of 1.9 (R11) being standard. The door on the south side of the sustainable house will have a full pane of glass and sidelight to allow maximum sunlight penetration. The north entrance door will have a half-operable window, for cross ventilation.

High Performance Windows

Poor window performance can significantly increase energy consumption which in turn increases space heating costs. A high performance window must minimize heat loss from the house, prevent cold winter drafts, minimize condensation and frost, allow maximum light to enter without overheating or glare and provide adequate ventilation. Double and triple glazed window units are to be used in the sustainable house in order to minimize heat loss. These state-of-the-art windows satisfy the standard criteria such as airtightness, maximum light, low glare and minimum condensation, and provide the highest insulation values against radiant and conductive heat losses.

Heat Mirror

Heat mirror glazing will only be used in front of the breadbox solar preheater. Heat mirror is an indium oxide coating that is suspended between the panes of glass in a double glazed unit. Unlike solar control films which reflect significant quantities of incident solar radiation, heat mirrors are highly transparent to shortwave and visible solar radiation. The result is an improvement in resistance with an allowance of 85 percent solar transmission.

Low 'E' windows are to be used on the south and east walls of the house. Low 'E' windows are double glazed units with a low emissivity coating. They have similar thermal and condensation

characteristics and admit approximately the same amount of light as triple glazed units. The advantage is less weight and bulk.

Small north and west triple glazed windows will be specified for the sustainable house. To maximize energy savings these window areas must be reduced to a minimum. The purpose of these windows is mainly to allow daylighting and ventilation. Utility rooms and bedrooms on the north side require least window areas.

Airlocks and Mudrooms
Both entrances to the sustainable house will have airlocks. Airlocks minimize the amount of heat lost when entering or exiting the house. Airlocks and mudrooms also create a barrier between the exterior and the interior. These areas can double as storage areas.

Energy Conserving Landscaping - Shelter Belt Foliage
It is possible through careful use of landscape elements such as trees, shrubs and fencing to reduce the heating and cooling loads of a house by 25 to 35 percent Shelter belt foliage is the planting of a grove of trees that will perform as a shading device as well as a windbreak. For instance, dense shrubs such as hemlock or spruce, when planted close to a building, affect its outside surface temperature by blocking or deflecting the wind, creating shade, and providing an insulating dead airspace between the shrub and building. Although the effect of landscaping is local and varies with the season, the weather, and the degree of growth, an appropriate combination of landscape elements can provide a valuable carbon dioxide sink and can reduce energy consumption. In addition the trees can reduce incident noise levels. The planting of deciduous trees on the south side of the house will let the sun in during the winter and provides shading during the summer. Coniferous trees are to be planted on the north side of the house to act primarily as a wind shelter belt.

The planting of high carbon dioxide absorbing trees (for instance, aspens, maydays, choke cherries, ornamental crabapples) is an essential component in slowing down the greenhouse effect. Each tree planted has the capability of absorbing more than 11.80 kilograms (26 pounds.) of carbon dioxide in a year.

Waste Recycling

Waste recycling is a viable method to conserve and reduce energy that is expended to manufacture and produce goods. But more importantly, it minimizes environmental damage caused by replacing those materials which are thrown away. A waste recycling center must become an important component in the house. It must address the three R's - reduce, reuse and recycle. These are features that demonstrate present day social requirements.

A recycling center with four recycling containers will be placed in the kitchen box window and will be accessible from both the inside and outside. The majority of waste occurs in the kitchen. These containers, then, would serve the purpose of conveniently separating the garbage at the major source. They will also facilitate composting and glass, metal and plastics recycling.

Recycled Building Materials

An attempt will be made to use recycled products for as much of the construction of the house as possible. Recycled tire pavers will be specified for the front walkway. Wood I-beam joists and roof rafters are made from recycled wood particles (wood chips, sawdust). All of the interior windows and doors will be constructed from recycled stock.

Low Maintenance Natural Materials

Wood shingles are considered a low maintenance material. They have a twenty-five year life span versus asphalt shingles that normally have a ten year span. In general, the use of materials

that are synthetic, chemically treated or require extensive energy to produce will be avoided. Certain materials that do not require continual maintenance, such as aluminum or vinyl siding are desirable, however, these products use enormous amounts of embodied energy to produce and as a result have a negative impact on the environment in general.

Less Use of Petrochemical Products

To the extent possible, materials that are not petrochemically produced but perform the same as those that are, have been specified (for instance, wood shingles instead of asphalt shingles). Materials manufactured from petrochemical products deplete natural resources. This in turn has a negative impact on the environment primarily due to the extraction and manufacturing process which produces carbon dioxide, volatile organic compounds, sulphur dioxide and nitrogen oxide particulates which are then released into the atmosphere. These products also have a negative impact on the indoor environment because of their outgassing characteristics.

5.7) Features and Design Considerations

This section presents some of the general design features chosen for the 'Sustainable House'. They do not necessarily represent departures from or innovations to conventional housing forms; rather, each was selected on the basis of its contribution to sustainability.

Slab-on-Grade Construction

The sustainable house will not have a basement. The traditional basement function can be accommodated above grade (see discussion on liveable attic, page 63), and the money saved by elimination of the basement can be applied to desirable sustainable features. From an embodied energy perspective, savings are realized through reduced mechanical excavation and reduced concrete quantities.

Slab-on-grade construction is fast and simple and requires minimal site excavation. It is quite compatible with radiant floor heating and will accommodate various floor finishing treatments.

Shallow footings are specified to support the slab. Sub-slab rigid insulation and lateral subgrade insulation at the footings will prevent frost penetration and subsequent heaving.

Optimization of House and Lot Sizes

To properly achieve energy consumption (including embodied energy) and environmental preservation goals, a conservation-oriented house should be designed to comfortably meet family needs with minimal area. This does not imply elimination of space, rather it implies optimization of space.

The following paragraphs describe the space planning process for the sustainable house.

Multi-Purpose Rooms

Some rooms can be combined to eliminate duplication. For instance there is no need to have a breakfast nook and a dining room. The dining room can accommodate both formal and informal dining. The family room can be eliminated and the living room can serve both purposes. Such reduction in space can translate into savings in capital, operating and environmental costs.

Liveable Attic

The attic is typically an unused space due to the webbing in trusses and low roof pitch (4 in 12). It is in most cases made practically inaccessible and therefore unusable. However, the sustainable house, with its 8 in 12 roof pitch and rafters instead of trusses allows the attic space to be habitable. It will provide additional rooms or space for living, storage and mechanical equipment. This practice is conventional in Europe.

The roof will be insulated between the rafters with dry-sprayed cellulose.

An additional feature of the roof is that it will not have an overhang on the east, west and north sides of the house. This will result in the saving of roofing materials, the use of shorter rafters and consequent consumption of less energy to produce these materials.

Car Port Instead of a Garage

The car port is a feature of the sustainable house that can be transformed into a garage in the future. Garages tend to use and occupy valuable land and require extensive energy to maintain and construct merely to house a vehicle. This is an expenditure that can be saved and applied to making the home energy efficient and environmentally sound. The garage is popular in many parts of North America, and the Alberta climate makes this a desirable, but expensive feature. In conventional housing, where the garage is not attached, it is generally not included in the selling price of the newly built home.

Pantry

A pantry is incorporated into the back entrance area and kitchen design as a means of having direct access to stored dry goods, garden produce and other foods. This is particularly appropriate for bulk food storage (now a common supermarket selling theme) and the pantry is a popular feature with most home owners/buyers.

Optimal Storage Space

All areas that are not useful living spaces should accommodate storage. For instance the risers in the stair will accommodate storage drawers.

Home Office

In the sustainable house, a home office will be incorporated into the design as an option that can replace the third bedroom. The future may well see decentralization of the office to the home to reduce energy consumption and carbon dioxide emissions as a result of not having to drive to work daily. The ability to install an exterior door to the office will also be incorporated as a design feature of the house.

Lot

On average, a single family lot size is 511 square meters (5500 sq.ft.) of which approximately 29 percent is used for a house and garage. The backyard comprises approximately 48 percent. The front and side yards usually comprise 23 percent of the property due to setback requirements. Since side yards are only used for access and front yards for lawns, each site could become smaller and be used in a much more practical manner. High carbon dioxide and sound absorbing vegetation, a composting area, an organic garden, play area and pond that can be used as a skating rink in the winter and for collecting rainwater run-off in the summer are important components of sustainability.

It should be noted that for the purpose of this report a standard conventional lot size of 50 feet (15.24m) by 110 feet (33.53m) will be specified.

The following section presents the design and specifications for the sustainable house which include all of the elements discussed above.

6.0) DESIGN and SPECIFICATIONS

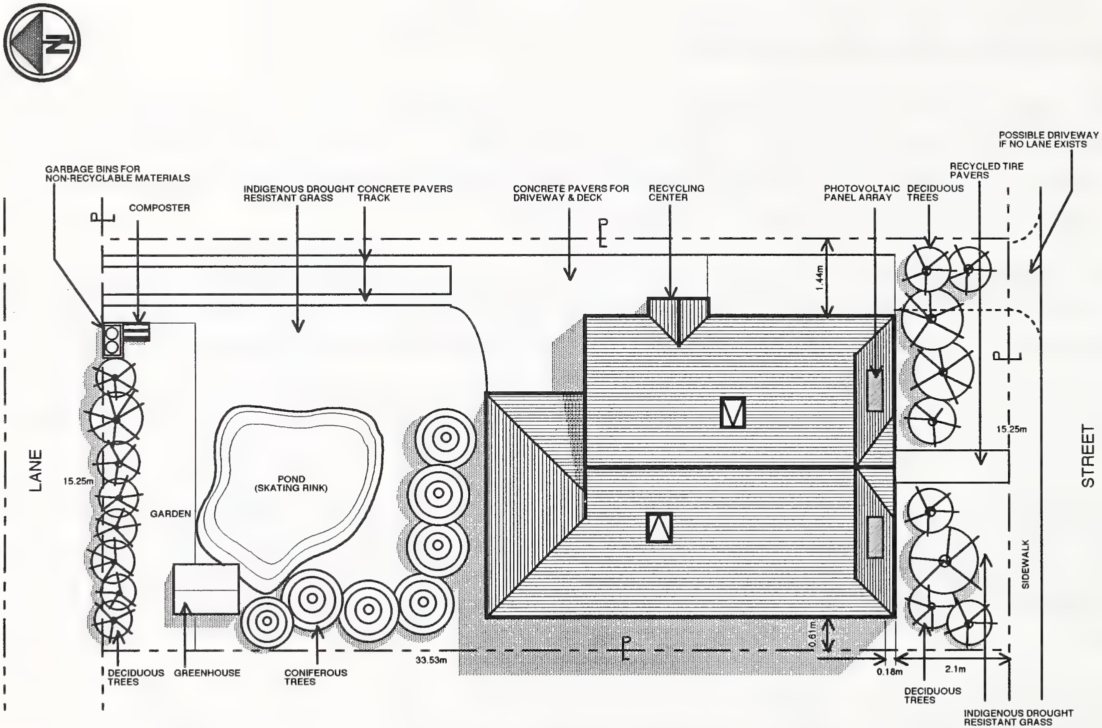
The sustainable house has been designed on a 12 foot (3.65 m) module which can accommodate factory prefabrication, which in turn can reduce material waste. Analysis indicated, however, that stick-building is the most cost-effective, therefore the preferred method. The 610mm (2'-0") on center framing system fits well within the 12 foot module.

The overall dimensions of the house are 36 feet (10.9 m) by 36 feet (10.9m). The foot print is 1290 square feet (120 sq.m), the net area of the main floor is 1175 sq.ft. (110 sq.m.) and the net habitable area of the attic is 375 sq.ft. (35 sq.m) for a total net habitable area of 1550 sq.ft. (144 sq.m).

Drawing A-1 is a generic site plan. It indicates areas of development, orientation and components that will make the site sustainable.

Drawing A-2 is the main floor plan consisting of three bedrooms, two bathrooms, a pantry, laundry, kitchen, dining room, living room and airlocks at the front and back entrances. The kitchen, dining and living room areas are open to the attic floor area above. Drawing A-3 shows the attic floor plan consisting of an open area, greenhouse, mechanical room, greywater cistern storage room and a storage area.

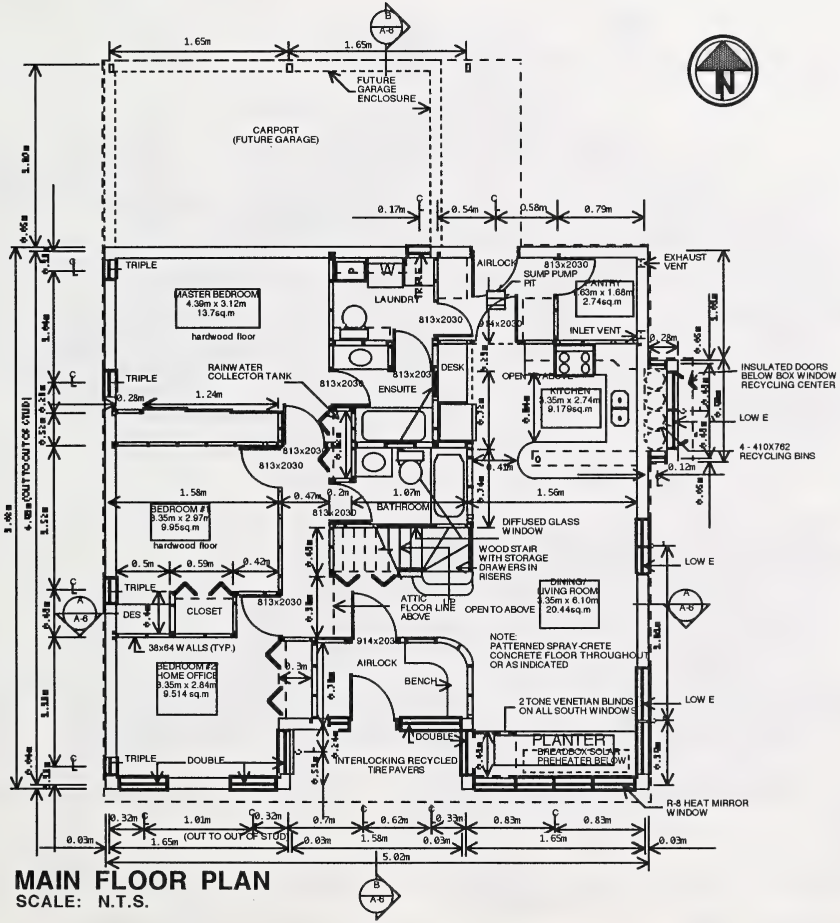
Drawings A-4 and A-5 describe the house in elevation views. Drawing A-6 shows building cross sections. Drawing A-7 contains both the electrical layout for the main floor and a schematic layout for the radiant floor heating system. Drawing A-8 describes the footing layout for the slab on grade. It also contains a list of specifications for the various components in the sustainable house.



SITE PLAN

SCALE: N.T.S.

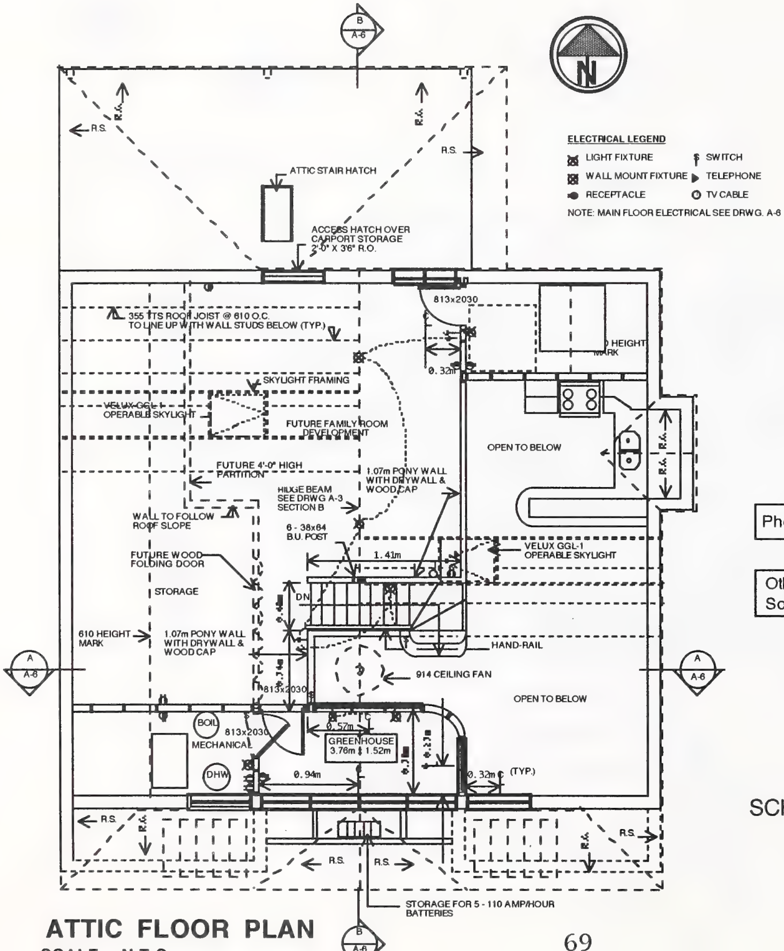
A-1



A-2

MAIN FLOOR PLAN

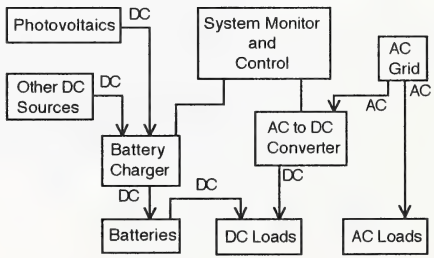
SCALE: N.T.S.



ATTIC FLOOR PLAN

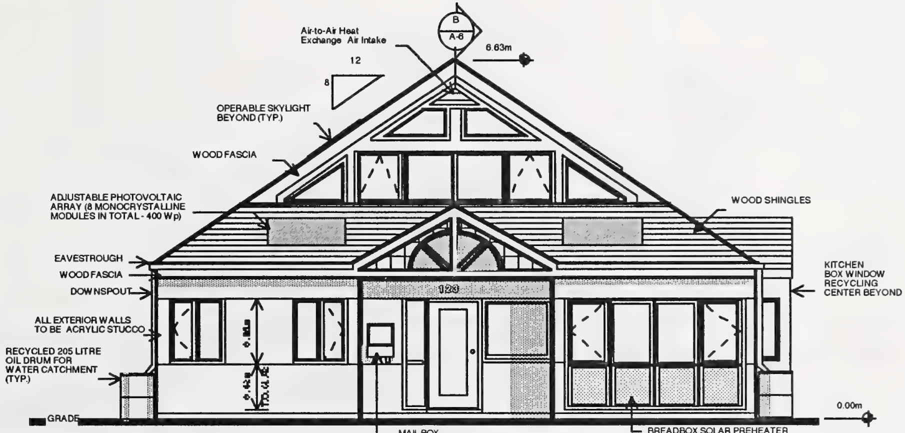
SCALE: N.T.S.

NOTE:
All outlets to be AC wiring except for the following:
a) DC power to all lighting fixtures;
b) DC power for mechanical equipment; in the mechanical room; for the fan and water pump;
c) DC outlet; for the refrigerator; in the carport; in the living room (stereo, television); on the kitchen counter.

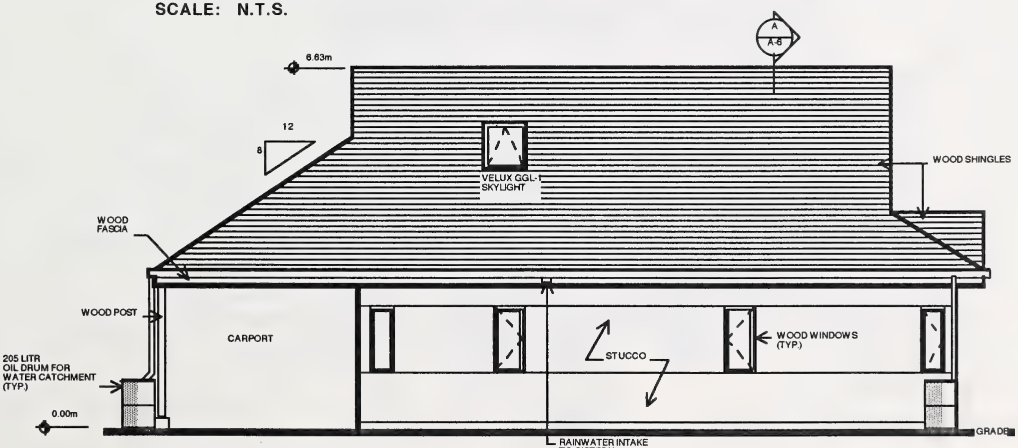


SCHEMATIC FOR PHOTOVOLTAIC SYSTEM

A-3

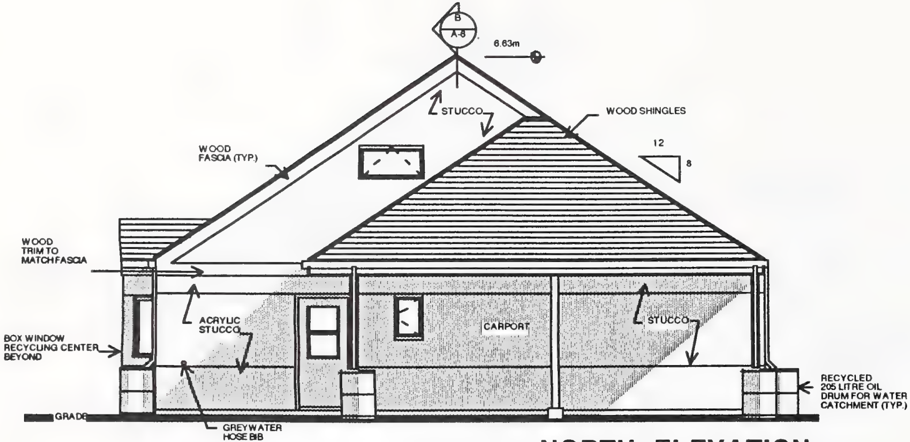


SOUTH ELEVATION
SCALE: N.T.S.

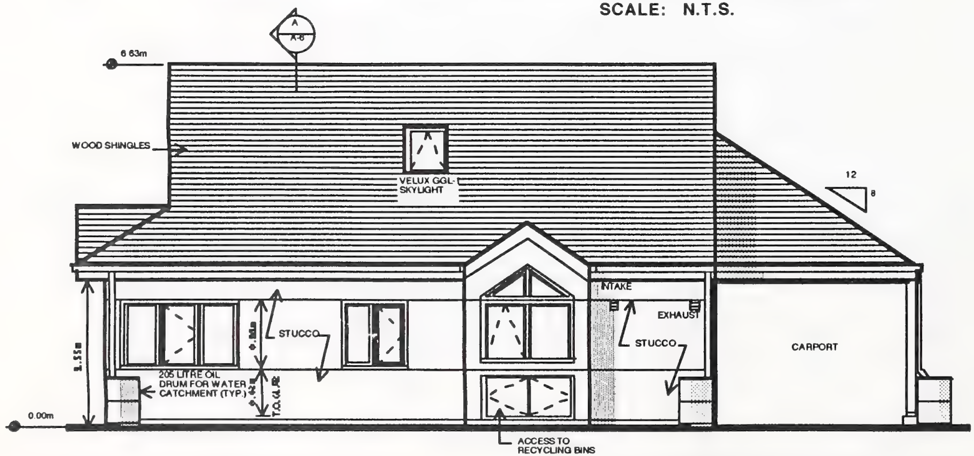


WEST ELEVATION
SCALE: N.T.S.

A-4

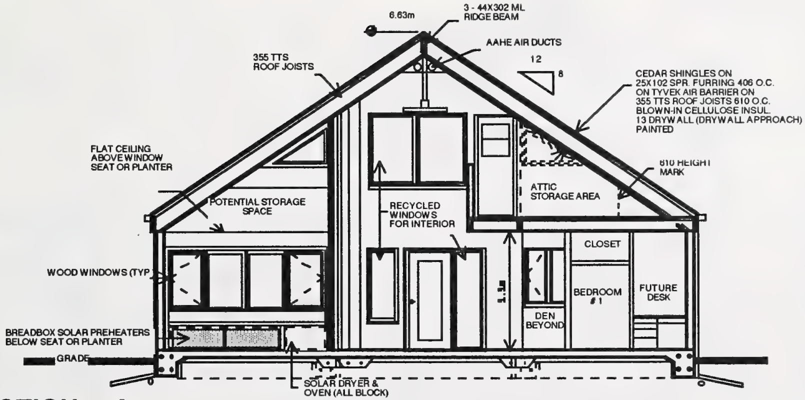


NORTH ELEVATION
SCALE: N.T.S.



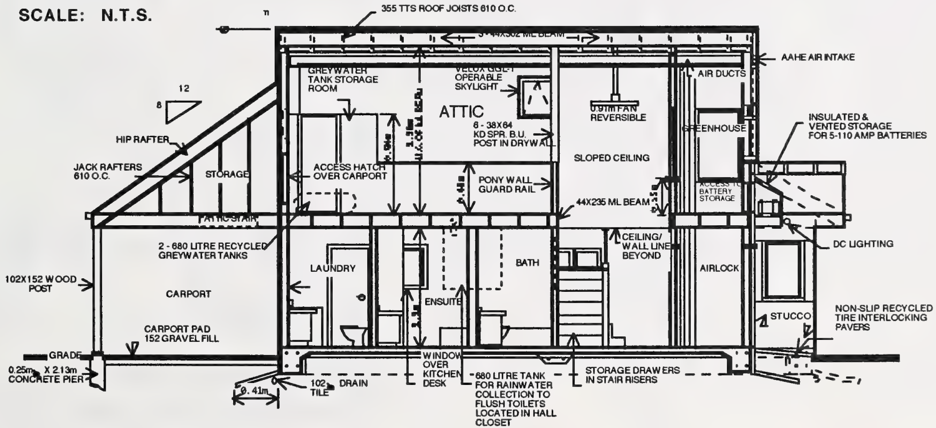
EAST ELEVATION

A-5



SECTION - A

SCALE: N.T.S.

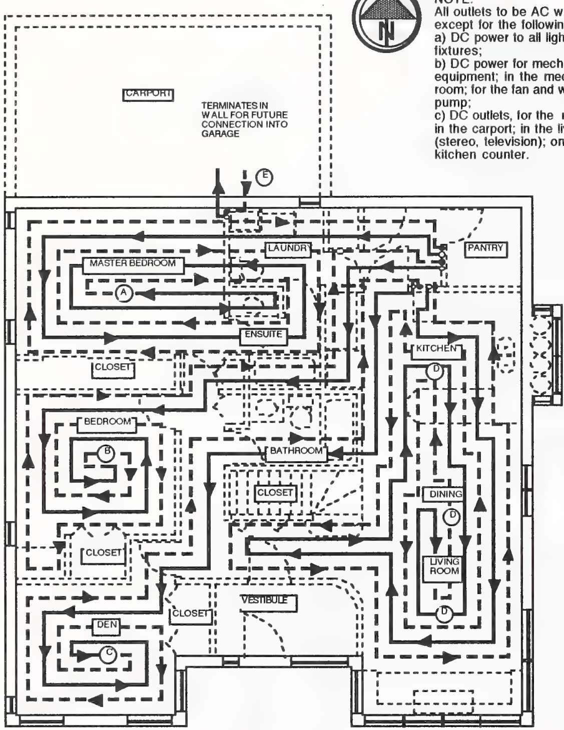


SECTION - B

SCALE: N.T.S.

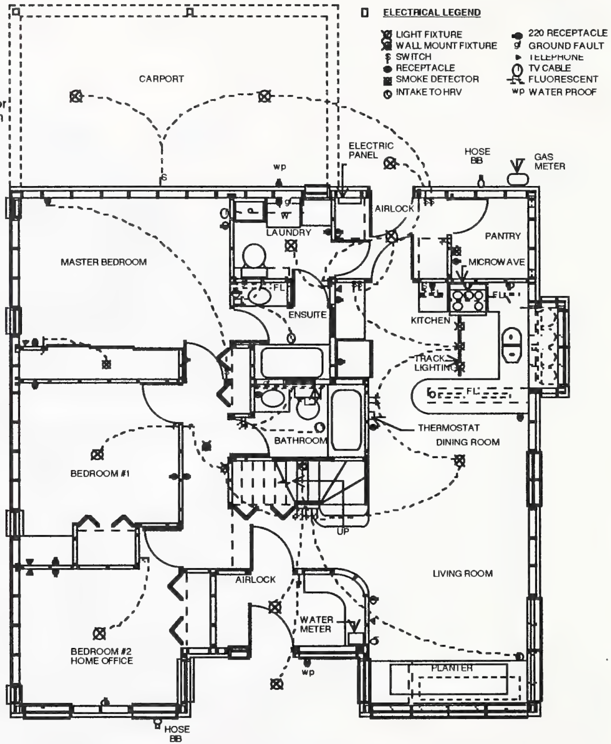
A-6

NOTE:
All outlets to be AC wiring except for the following:
a) DC power to all lighting fixtures;
b) DC power for mechanical equipment; in the mechanical room; for the fan and water pump;
c) DC outlets, for the refrigerator in the carport; in the living room (stereo, television); on the kitchen counter.



MAIN FLOOR RADIANT LAYOUT

SCALE: N.T.S.

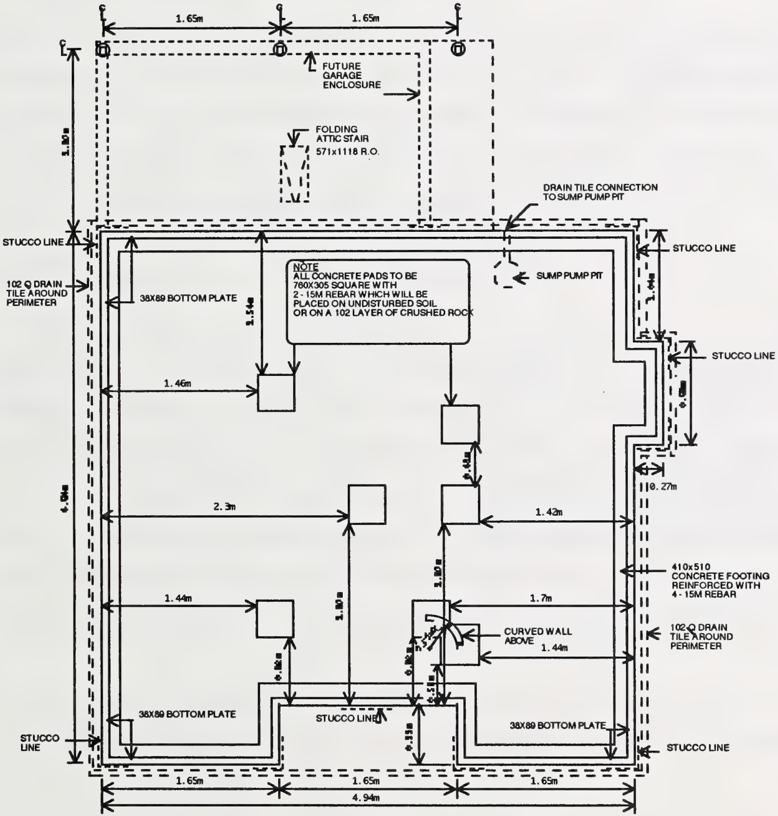


MAIN FLOOR ELECTRICAL PLAN

SCALE: N.T.S.

(SEE DRWG. A-3 FOR ATTIC ELECTRICAL LAYOUT)

A-7



FOUNDATION PLAN
SCALE: N.T.S.

SPECIFICATIONS

FOUNDATION
- 20 Mpa, type 50 concrete in 410x510 reinforced footing
- 2 rows of 15M rebar
- 100mm concrete slab reinforced with 150x150 9/9wwm
- 250mmx2.13m deep conc. piers in carport area
- 100mm dia. weeping tile c/w 150mm washed gravel

FRAMING
- 240mm TTS joists @ 610 o.c.
- microlam beams on b.u. wood posts
- 12mm O.S.B. attic subfloor
- exterior wall 38x140 KD spruce @ 610 o.c.
- interior walls 38x64 KD spruce @ 610 o.c.
- 25x89 diagonal let-ins
- 63mm EPS type 2 rigid insulation as sheathing
- 355 TTS roof joists 610 o.c.

INSULATION / VAPOUR BARRIER / DRYWALL
- exterior walls R20 blown-in dry cellulose
- ceilingR53 blown-in cellulose
- 50mm EPS Type 2 rigid insulation under slab
- 12mm gypsum wallboard
- Airtight Drywall Approach

EXTERIOR FINISHES
- acrylic stucco and wood trim
- wood shingles on 25x89 strapping

DOORS AND WINDOWS
- insulated front & back doors
- wood windows (low-e, heat-mirror, double & triple)
- solid core interior doors

INTERIOR FINISHES
- solid wood cabinetry & railing
- textured concrete slab with
- hardwood flooring in bedrooms
- wood trim

PLUMBING AND HEATING
- radiant floor heating
- heat recovery ventilator
- breadbox solar preheater
- 152 liter gas water heater
- greywater cisterns
- rainwater cistern
- 0.6 liter low flush toilet
- low flow faucets throughout
- 2 - 3 piece baths
- water meter

ELECTRICAL
- 40 amp, 16 breaker electric service
- fluorescent task lighting in kitchen
- 6 telephone locations
- 3 cable locations
- smoke detectors
- 2 exterior weatherproof plugs
- bathroom & kitchen fans hooked up to HRV
- GFCI plugs in bathrooms
- 915mm ceiling fan
- adjustable photovoltaic array (8 monocrystalline modules in total - 400 Wp)
- 5 - 110 amp per hour batteries

A-8

7.0) COMPARATIVE PERFORMANCE

The performance of the 'sustainable house' design can be predicted in terms of the criteria explained in Section 5. An indication of how well the goals of sustainability have been achieved can then be obtained through comparison of the results to those of a conventional house similarly analyzed. In the following subsections, where appropriate, consumption figures per thousand square feet of house are used for comparative purposes to avoid the obvious anomalies that might result from comparisons drawn on the basis of differently sized houses.

7.1) Lumber

A conventional house uses an average of 145-185 trees per 93 sq. meters (1000 sq. ft.) of house. Based on a lumber materials takeoff, it was determined that the sustainable house incorporating the features detailed in Section 5, would use an average of 115-145 trees per 93 sq. meters (1000 sq.ft.) of house. It is estimated then, that the sustainable house will require 20 percent less lumber to build than a similarly sized conventional house. This savings can be attributed to various factors, including the use of a 600mm-on-center framing system instead of the typical 400mm-on-center framing system, the use of roof rafters instead of trusses, the elimination of wood sheathing on the exterior walls and roof and replacement with diagonal 1x4 wood let-ins and wood shingles on 1x4 strapping respectively, and the elimination of roof overhangs on the east, west and north sides. Additionally, the modular design of the sustainable house should result in minimal waste as it is based on dimensional lumber sizes.

With the use of wood-I's for attic floor joists, a further saving in dimensional lumber material can be achieved because the wood-I's incorporate recycled lumber in the webs.

7.2) Electricity

It is estimated that the 144 square meter (1550 sq.ft.) sustainable house with a four person household will require 330 kilowatt hours of electricity per month (213 kWh per month per 1000 sq.ft.) which was established by integrating an AC-DC system with an array of 8 photovoltaic panels and with the specification of energy efficient appliances and lighting (see Appendix 2, part D and Appendix 3 for further information concerning electrical consumption). Compared to a conventional four person household that requires approximately 750 kilowatt hours of electricity per month per 1000 square feet, a statistic provided by the City of Calgary Utilities Department, the sustainable house is expected be capable of reducing electrical consumption by approximately 72 per cent.

7.3) Water

A four person household in a conventional house will typically consume 425,160 litres of water per year. It is estimated that a four person household in the sustainable house will only consume 142,400 litres of municipal water per year, based on calculations using consumption figures relating to the recycling of rainwater and greywater and the use of low flushing volume toilets and low flow faucets (see Appendix 2, part C). The design characteristics of the sustainable house's water supply and distribution are therefore capable of assisting in the reduction of conventional water consumption by up to a factor of four.

7.4) Heating/Cooling

Heating was calculated on the basis of natural gas consumption. The amount of natural gas that is typically used in a 1550 square foot conventional house in Calgary is 175 gigajoules per year (113 GJ per year per 1000 square feet) for a forced air furnace and domestic hot water heater. The total

estimated amount of natural gas used in the sustainable house was calculated to be 37 gigajoules (24 GJ per year per 1000 square feet). This was derived from Hot2000 (version 5.07) heating calculations that are based on the efficiency of the boiler for the radiant floor heating (87%) and domestic hot water heating requirements. The breadbox solar water preheater will supply about 37 percent of total water heating load and passive solar would provide about 40 percent of total space heating requirements.

Therefore, the four person household in the sustainable house should consume approximately only 21 percent of the natural gas per year (for a furnace, domestic hot water tank, range and dryer), compared to a conventional house. A proportional reduction in carbon dioxide production, from 9.1 tonnes to 1.9 tonnes, would also result.

7.5) Indoor Air Quality

It is difficult to make indoor air quality comparisons between houses because lifestyle of the occupants is a major controlling variable. Consequently, the authors were not able to calculate a degree of improvement in the air quality of the sustainable house as compared to a conventional house. However, by design, the sustainable house reduces to the extent possible the sources of pollutant materials listed in Table 7. For instance, materials that contain phenols and aldehydes, such as carpeting, were eliminated (carpeting is a major collector of pollutant particles), the use of natural wood materials was specified instead of particleboard products and the use of a paint product that seals materials and eliminates outgassing was specified. In addition, appliances and electrical fixtures that produce low levels of electromagnetic pollution were chosen and specified for the sustainable house.

Appendix 2, part E, lists target maximum levels of pollutant concentrations for the sustainable house. Though these levels represent substantial improvement over corresponding levels of Table 7, the comparison should be interpreted objectively rather than deductively.

7.6) Energy Impact

It is difficult to establish an embodied energy total at present due to a lack of relevant information on many components (for instance stucco). It is, however, anticipated that the energy impact of the sustainable house will be substantially lower than that of a conventionally built house simply because selecting materials of low embodied energy value was a major design consideration.

Embodied energy statistics are not readily available at present, but there is ongoing research that has the objective of developing computer software capable of calculating the total energy used in the construction and operation of a house. It is the intention of the authors to test the sustainable house once this software is made available.

Many of the design decisions for the sustainable house were influenced by available embodied energy calculations. For instance, a recycled fibre-board was initially selected for the exterior sheathing. However, when the product was examined in terms of embodied energy, it was found to be less desirable than extruded polystyrene and it was eliminated as a potential product for the sustainable house. Where applicable, this process was also employed in the subsequent costing analysis to justify the cost effectiveness of certain materials chosen for the sustainable house.

8.0) COST ANALYSIS

To compete and succeed in the marketplace, the sustainable house must be cost effective in its own right, with a selling price comparable to a similarly sized conventional house. Selling features and advantages include lower operating costs, greater comfort, less construction time and environmental sensitivity. The house is designed to promote sustainable development with minimal compromise on the part of the homebuyer.

The cost of the sustainable house takes marketability into account. The issue of placing a monetary value on some aspects of sustainability is sometimes difficult to accept; however, in a market that is driven by consumers, cost becomes a crucial determinant of a product's success or failure. Marketable features that will be accepted by the house buying public are those that are not difficult to understand in terms of function and are not difficult to install by the average tract builder.

The consumer should be made aware of the negative environmental impact of certain features in conventional houses through a comparison of features that perform similar functions. One such example is the natural gas forced air furnace that depends on energy from a non-renewable fossil fuel, whereas a radiant floor heating system can depend on and be integrated with solar energy. The capital cost is much higher for the radiant floor heating system, but it will have a lesser impact on the environment and on the indoor air quality of the home. The design of the generic sustainable house has features that are both environmentally sensitive and marketable.

8.1) Target Cost

The three-bedroom, four-level split house utilized by Alberta Municipal Affairs for its annual House Cost Comparison Study, was taken as the benchmark conventional house for pricing purposes. In the

1990 version of the study, the "hard" cost of the benchmark house was reported as $52.42 per square foot. "Hard" costs exclude land and site development costs, design and legal fees, marketing and realtors fees, appliances, and general contractor's overhead and profit.

The following pricing structure was used to establish the maximum selling price for the sustainable house:

- hard cost as reported in the 1990 House Cost Comparison Study ____________ $52.42 per sq.ft.
- 5 percent incremental cost allowed, providing the increment can be offset by credible paybacks (utility savings, for instance) ____________ $2.62 per sq.ft.
- contractor's overheads and profits included as 20 percent of the selling price ____________ $13.76 per sq.ft.

Total Allowable Selling Price of the Sustainable House ____________ $68.80 per sq.ft.

8.2) Determination of Actual Selling Price

The design drawings and specifications were provided to three reputable builders for material takeoff, price quotation and practical criticism. Simultaneously, one complete set of drawings and specifications were submitted to the City of Calgary Building and Planning Department for compliance review and practical criticism.

Criticisms were reviewed, and, for those deemed valid, the builders were requested to incorporate corrections for pricing purposes. Submitted prices were averaged, and the resultant average total was compared to the allowable total of Section 8.1. Where reductions were required, features of the sustainable house were eliminated in the order of least preference. Appendix 4 lists all of the

features considered for the sustainable house, and indicates those that were eliminated for cost or practical purposes. The features of Section 5 are those that survived critical and cost reviews.

Table 10 provides an itemization of the final cost of the sustainable house, and a comparison to similar trade categories in the benchmark conventional house. To illustrate the eliminative process used, Table 10 is shown in the form of its next-to-last iteration. The total cost for the sustainable house of $86,906.00 represents a unit cost of ($86,906.00/1550 sq.ft.) $56.07 per square foot. Adding the overhead and profit component as required by Section 8.1 yields a total selling price of ($56.07 per sq.ft. / 0.8) $70.09 per square foot. This value exceeds the allowable total of $68.80 per square foot by $1.29 per square foot, which means that ($1.29x1550 sq.ft.) $2000.00 must be trimmed from the cost of the sustainable house. To meet this requirement, it was decided that the cost, therefore the scope, of the photovoltaic (PV) system must be reduced. The photovoltaic system is very desirable from an environmental perspective. However, it is a high capital cost item, and at this final stage of development, it represents the least desirable feature. The reduced cost of the photovoltaic system is calculated as follows:

- Present Selling Price of PV System = $8,000 / 0.8 = $10,000.
- Reduced Selling Price of PV System = $10,000 - $2,000 = $8,000.
- Reduced Hard Cost of PV System = $8,000 x 0.8 = $6,400

Therefore, to achieve the reduction required, the photovoltaic system must be reduced in scope such that its hard cost does not exceed $6,400.00. (The specification on page 74 describes the photovoltaic system as it must be to meet price limitations).

Table 10 - Cost of Materials and Installation

	HOUSE	Conventional	Sustainable
#	MATERIALS / TRADES	QUOTES	QUOTES
1	SITE WORK		
a.	excavation & backfill	$3,384	$1,600
	SUB-TOTAL	**$3,384**	**$1,600**
2	CONCRETE WORK		
a.	foundation - gravel	$10,922	$1,200
b.	slab on grade		$2,080
c.	drain tile		$250
	SUB-TOTAL	**$10,922**	**$3,530**
3	CARPENTRY WORK		
a.	rough carpentry materials	$14,933	$13,810
b.	finish carpentry materials	$2,525	$4,120
c.	roof rafters , joists & beams		$6,275
d	stair		$445
	SUB-TOTAL	**$17,458**	**$24,650**
4	MECHANICAL		
a.	plumbing & heating system (radiant floor heating) complete.	$9,430	$10,400
b.	air-to-air heat exchanger		$1,500
	SUB-TOTAL	**$9,430**	**$11,900**
5	ELECTRICAL		
a.	wiring, distribution & fixtures	$4,086	$2,680
b.	photovoltaics		$8,000
	SUB-TOTAL	**$4,086**	**$10,680**

	HOUSE	Conventional	Sustainable
#	MATERIALS / TRADES	QUOTES	QUOTES
6	THERMAL & MOISTURE		
a.	pine shingle roofing & flashing	$2,198	$2,080
b.	soffit, fascia & eaves		$896
c.	insulation under slab		$520
d	interior insulation - cellulose	$2,240	$2,800
e	exterior EPS & Stucco Wire		$1,800
f.	Doors & Windows	$6,831	$7,200
	SUB-TOTAL	**$11,269**	**$15,296**
7	FINISHES		
a.	stucco	$5,944	$3,200
b.	drywall, taping & ceiling	$4,738	$3,300
c.	painting	$2,890	$2,000
d	flooring (complete)	$3,868	$1,200
	SUB-TOTAL	**$17,440**	**$9,700**
8	SPECIALTIES		
a.	breadbox solar preheater, rainwater & greywater cisterns	$736	$1,000
	SUB-TOTAL	**$736**	**$1,000**
9	FITTINGS		
a.	kitchen cabinets & vanities	$4,700	$2,800
	SUB-TOTAL	**$4,700**	**$2,800**
10	SITE OVERHEAD	$5,750	$5,750
	SUB-TOTAL	**$5,750**	**$5,750**
	TOTAL	**$85,175**	**$86,906**

8.3) Paybacks

The allowable selling price for the sustainable house, as noted in Section 8.1 requires that the incremental portion be offset by credible paybacks. The amount that must be recouped is calculated as:

Capital Payback Required = Hard Cost Increment + Associated Overhead and Profit
= Hard Cost Increment ÷ 0.8
= \$2.62 per square foot ÷ 0.8
= \$3.28 per square foot x 1550 square feet
= \$5,084.00

The sustainable house contains many features that represent intangible paybacks. For instance, reduced toxicity in building materials could result in reduced medical costs. This discussion, however, will focus on payback items to which monetary values can easily be assigned. Specifically, utility costs will be discussed.

From Section 7, it was seen that substantial savings can be achieved through reduced electricity, natural gas, and, where revenue meters are required, water consumption. Annual electrical consumption can be reduced by as much as 537 kWh per month per 1,000 square feet, which, for the sustainable house represents a savings of 9,988kWh per year (the occupants of a sustainable house will use 3,962 kWh of electricity per year). At a typical rate of 5.5 cents per kWh, this, in turn, represents an annual saving of \$550.00. Similarly for natural gas, annual consumption could be reduced by up to 138 GJ (the occupants of a sustainable house will use 37 GJ of natural gas per year for space and water heating), which at a typical cost of \$3.15 per GJ, represents an annual saving of \$435.00. Residential water consumption is not metered in Calgary, but, for Alberta municipalities that require metering, a reduction of annual consumption by up to 283 cubic meters (the occupants of a sustainable house will use 142.4 cubic meters of water per year) at a typical blended cost of \$0.77 per cubic meter could result in an annual savings of \$218.00.

The resultant total annual cost savings for electricity, natural gas and water consumption could total \$1,203.00. Payback of the incremental cost (\$5,084), then, could be achieved within five years. It

must, however, be realized that the figures used to calculate this period represent potential maxima. Various tempering circumstances must be considered:

- To achieve the overall selling price target, the photovoltaic system must be reduced in scope from that described in Section 5. The reduction could consist of eliminating two solar panels. The photovoltaic system then, would power the refrigerator , and a select number of DC appliances. This would increase the electrical consumption slightly.

- Lifestyle variations could significantly affect the consumption scenario. For instance, the sustainable house has been designed without provision for a gas or electric clothes dryer. For some, perhaps many, this would not be an acceptable departure from convention, and the installation of a clothes dryer would increase consumption of natural gas or electricity by approximately ten percent.

- Where water is not presently metered and billed, a cost savings allowance for reduced consumption is meaningless.

All of the above circumstances tend to increase the payback period. However, the calculated payback time can suffer considerable degradation before it is deemed non-feasible. Simple payback over ten years is generally deemed acceptable. The cost savings calculated in this section could therefore be reduced by as much as one-half and still result in an acceptable payback scenario.

8.4) Cost Summary

By reducing the scope of the photovoltaic system described in Section 5, the target selling price of $68.80 per square foot was achieved. Included incremental costs of $3.28 per square foot can be regained in utility savings in a five-to-ten year period.

9.0) CONCLUSIONS

Sustainable housing is achievable and has been achievable for quite some time. However, conventional housing has not yet addressed sustainability; but given that consumer attention has been turned to the environment, the need for conventional housing that is also sustainable is upon us.

To succeed in the consumer-driven housing industry, the sustainable house must possess certain market entry characteristics:

- it must be feasible; and
- it must be sellable.

These characteristics can be broken down further into the following attributes:

- the sustainable house must maximize the use of environmentally protective methods and materials;
- it must minimize the impact of change to accepted lifestyles;
- it must be attractive in the sense that builders are encouraged to build and market it; and
- its price must be competitive with today's conventional house.

This project has produced a design that addresses these characteristics and attributes. Recognizing that the house, as designed, may not be attractive in all ways to all consumers, it was designed with versatility in mind. When considering modifications however, it will be important to maintain balance among the listed attributes. The design is, itself, an example of this exercise. Recycled fibre board was considered for exterior wall sheathing, but was not selected because of its high embodied energy and cost. Instead, extruded polystyrene was chosen. Similarly, composting toilets were considered,

but rejected because the adverse effect on lifestyle and urban marketability would outweigh the environmental benefit. When selecting a house of this or other sustainable design, a homebuyer must also make the same sort of decisions. Choosing a basement instead of slab-on-grade construction for instance, might require that the attic space not be developed to a habitable level, to balance the cost equation.

The construction of affordable, sustainable housing is well within the present abilities of the industry, and present and future homebuyers are becoming aware of the importance of environmental sustainability. The construction of housing that responds to this awareness will undoubtedly produce long term benefits for all concerned and, most importantly, for the environment. Sustainable houses could come complete with performance rating labels, similar to those used by the auto and major appliance industries, demonstrating to homebuyers that their purchase is more than the largest single investment of their lives - it is also an investment in the preservation of the global environment.

At the time of this report, the authors are investigating several demonstration possibilities and opportunities.

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APPENDIX 1

Sustainable House Questionnaires

TO: ____________________ OF: ________________________ FROM: ________________________

MESSAGE: ____ DATE: ______________

We are currently designing a generic 'Sustainable House' for tract builders.

SUSTAINABLE HOUSE - Definition: A sustainable house is an ecologically sound house that will reduce environmental impact and will contribute to meeting the needs of the present without compromising the ability of future generations to meet their own needs.

QUESTIONNAIRE: For the purposes of this study, your input is requested. Please make copies for any other interested parties. If appropriate please copy and insert in any newsletter. We will be happy to inform you of the results, if requested. Additional information is appreciated. Thank you for your cooperation.

1. Please recommend any relevant **article/book** on the subject: [ ] Copy Enclosed

2. Do you know of any existing or planned **examples** of such housing anywhere and their **contacts**?:

3. Does the housing industry have an interest or an **awareness** of the concept of environmental sensitivity?: ____

4. What is the housing industry's **extent of acceptance** of housing that is oriented towards environmental sensitivity and on what **condition**?: ______________________________

5. How can conventional new housing in general be made more **sustainable**?:

6. What other **specific features** should be incorporated into an environmentally responsible new home?:

____

____

____

7. What other **criteria or parameters** should be considered in evaluating housing that integrates optimal but realistic environmental sensitivity? Give Examples :

____

____

8. What present **marketing trends** in housing, can assist in the promotion and acceptance of environmentally sustainable features?: ____

____

____

9. Are frontyards, basements, formal dining rooms and family rooms necessary or redundant? Why?:

____

____

10. What else should be done by government, code committees, building permit officers, city councils, developers, builders, general public, the media and educators, to make housing more sustainable?:

____

____

____

11. Is the general public interested in an environmentally responsible house? Why?:

____

____

12. Will the public purchase such a home? At what price (or incremental price increase) for what size

a home? And with what features?: ______________________________

____

____

13. Anyone else (at what address, phone and fax #) to whom we should send this questionnaire?: ______

____

14. **For a builder/developer/owner-builder/sub-trade:** Have you built such homes? Please list whatever features considered environmentally sensitive that are practical, cost-effective and marketable: ______________________________

____

____

15. What is the average **size and cost** of your home? ______________________________

Any additional comments or suggestions?: ______________________________

____

____

____

Name: ______________ Occupation: ______________

Affiliation: ______________________________

Address: ______________________________

____

Date: ______________ Phone/Fax: ______________

____

ALTERNATIVE & CONSERVATION ENERGIES INC., VARSITY EXECUCENTRE

Varsity Estates Dr. N.W. Calgary Alberta T3G 2W9, Ph: (403) 239-1900, Fax: 286-1407

TO: OF: FROM: DATE:
MESSAGE:

The following questionnaire is supplemental to the 'Sustainable House' questionnaire. Your response, comments and opinions is requested and will be greatly appreciated. Please add additional items to the list that may be considered appropriate. Thank you.

NO.	FEATURES	PRACTICAL	MARKETABLE	COST EFFECTIVE	COST ($)
1	HEATING				
	a) Greenhouse / Solarium				
	b) Solar Hot Air Heating				
	c) Radiant Floor Heating				
	d) Air-to-Air Heat Exchanger				
	e) Large South Windows				
	f) Interior Solar Heat Sink				
	g) Natural Cooling				
	h) Large (Casa-Blanca) Ceiling Fan				
2	WATER				
	a) Solar Hot Water Heater				
	b) Waste Water Heat Exchanger				
	c) Water Conservation				
	d) Water Meters				
	e) Waste Water Recycling				
	f) Low Flush Toilet				
	g) Waterless Toilet				
	h) Rain Water Collectors				
3	ELECTRICITY				
	a) Maximum Daylighting				
	b) Photovoltaics (solar electric panels)				
	c) Solar Clothes Dryer (clothesline)				
	d) Energy Efficient Appliances				
	e) Smart Technology				
	f) Energy Efficient Lighting				
4	CONSERVATION				
	a) Stricter Building Code				
	b) Higher Levels of Insulation				
	c) Air-Tight Construction				

NO.	FEATURES	PRACTICAL	MARKETABLE	COST EFFECTIVE	COST ($)
4	**CONSERVATION (con't)**				
	d) Weather Strpping & Caulking				
	e) High Performance Windows				
	f) Small North, East, West Windows				
	g) Airlocks / Mudrooms				
	h) Energy / Water Cost Indicator				
	i) Set-Back Thermostats				
	j) Built-In Recycling Containers				
	k) Less Use of Depleting Sources				
	l) Energy Conserving Landscaping				
	m) Garden Compost Pile				
	n) Organic Garden				
5	**ARCHITECTURAL**				
	a) Low Maintenance Materials				
	b) Pre-Fabricated Houses				
	c) Slab on Grade Construction				
	d) Shallow Footings				
	e) No Basement				
	f) Smaller House				
	g) Open Plan				
	h) Multi-Purpose Rooms				
	i) Porch				
	j) Car Port vs. Garage				
	k) Cold Storage Room				
	l) No Fireplace				
	m) Livable Attic				
	n) Home Office				
	o) Rental Suite				
	p) Local (natural materials) vs. Imported				
	q) Do-it-yourself Features to Save $				
6	**OTHER**				
	a) Air Pollution Monitor				
	b) Low Indoor Air Pollution				
	c) Air & Water Filtration				
	d) Smaller Lots				
	e) Place Heating Appliance Outdoors				
	f) Environmental Performance Rating				
	g) Self Sufficiency				

A.C.E. - ALTERNATIVE & CONSERVATION ENERGIES INC.,
VARSITY EXECUCENTRE: 1700 Varsity Estates Dr. N.W. Calgary, Alta., T3G 2W9 Ph. (403) 239-1900, Fax. 286-1407

APPENDIX 2

Performance Standard Guidelines

The following guidelines were taken from a Saskatchewan Research Council (March 1991) document prepared by Robert S. Dumont titled "Advanced Concepts Homes Field Trials - Technical Requirements". These guidelines are intended to ensure a consistency in the building of housing that is energy efficient and environmentally sound from the quality of indoor air to the manner materials are selected and used.

The following guidelines are a set of targets that can be achieved. However, the actual values and results can only be established once the home is built, occupied and monitored over an extended period of time. Certain components for instance cannot be completed until the house is built ie. wind speeds.

A. Statistics:

1) House:	a) Habitable Area:		1,550 sq.ft. (144 sq.m.)
	b) Number of Bedrooms:		3 - one can act as den/office
	c) Number of Bathrooms:		2
	d) Total Heated Volume:		459 cubic meters
	e) Cost Per Square Foot:	Hard:	\$56.07 / sq.ft.
		Soft:	\$68.80 / sq.ft.
	f) Construction Time:		3 months
	g) Year of Construction:		1992
	h) South Window Area:		12 sq.m. (130 sq.ft.)
	i) Internal Mass:		Stud walls, construction waste, slab on grade
	j) Foundation System:		Slab on Grade
	k) Site Orientation:		North - South (south on street side)
2) Site:	a) Geographic:		51^{o} 02' N Lat., 114^{o} 05' W Log
	b) Location:		Urban (City of Calgary)
	c) Lot Size:		15.25m x 33.53m (50ft. x 110 ft.)

3) Climatic:	a) Degree days (deg. C):	Heating:	5365 (Environment Canada)
	b) Total Sunshine Hours:	Winter:	Oct.-Apr. 1320
		Summer:	May-Sept. 995
	c) Wind Speeds (Avg.):	Yearly:	16.2 km/h NNW
	d) Design Temperature:	Winter:	-31 deg.C (2.5%)
	e) Design Temperature:	Summer:	+29 deg.C (2.5%)
	f) Global Solar Radiation	(horizontal):	13.51 MJ/m^2
	g) Direct Solar Radiation	(51^{o}. angle):	17.21 MJ/m^2

B. Energy Targets:

1) Target Annual Space Heating:	<6,770 kWh
2) Annual Total Energy:	10,270 kWh per year
3) Annual Total Energy Consumption per Unit of Heated Volume:	22.4 kWh per cubic m.
4) Annual Total Energy Consumption per Unit Floor Area:	<52 kWh per sq.m.
5) Primary Heat Sources:	- Passive Solar (direct gain Space Heating) - Passive Solar Domestic Water Preheater - Warm Air Destratification
6) Insulation Levels: a) Ceiling:	RSI-8.8 (R-50)
b) Walls:	Above grade: RSI-5.6 (R-32) Below grade: N/A
c) Slab:	RSI-2.1 (R-12)
7) Air Tightness (ACH at 50 Pa):	<1.5 ACH

9) Base Loads:	a) Sensible Heat Gain from Occupants; 2kWh per day.		
	b) Daily Base Electrical Consumption; 5 kWh per day.		
	c) Daily Hot Water Consumption; 186 liters per day.		
10) Average Ventilation Rate:			0.35 ACH
11) Seasonal HRV Efficiency:			67%
12) Auxiliary Heating Fuel:			Natural Gas
	a) Boiler = @ 27.4 GJ		
	b) DWH = @ 9.3 GJ		
	c) Total = @ 36.7 GJ		
13) Primary Space Heating System:	a) Direct Passive Solar Heat Gain		
	b) Radiant Hydronic Floor Heating		
14) Domestic Hot Water:	a) Primary Domestic Hot Water Heating System:		Passive Solar Preheater
	b) Minimum Equipment Insulation:		RSI 3.5 (R-20)
	c) Minimum Pipe Insulation:		RSI 0.9 (R-5)
15) Solar	a) Space Heating:		Concrete slab to be primary solar heat sink
	b) Cooling Techniques:		- air tightness
			- higher levels of insulation
			- thermal mass
			- cross-through ventilation
			- chimney effect ventilation
			- reflective blinds

C. Environmental Performance:

1) Ozone Depletion Factor: 0.03

2) Maximum Water Consumption:

a) Total:	@ 100 liters per person per day	
b) Toilet:	450 ml (1 quart)	
c) Low flow Shower Heads:	9 litre per minute (2 gallon per minute)	
d) Aerator Faucet:	12.5 litre per minute (2.75 gallon per minute)	

Average Annual Demand (4 person household)

Toilet	2.5 m3	1.7%
Shower (5 min.)	57.60 m3	40.5%
Faucet (minutes)	0.80 m3	0.6%
Dishwasher	37.80 m3	26.5%
Clothes Washer	34.50 m3	24.2%
Faucet (minutes)	9.20 m3	6.5%
Leaking Faucet	Proper maintenance	N/A
Lawn Sprinkler	Use of Greywater	N/A
TOTAL:	142.4 m3	100.0 %

(Note: Water for toilet can be reduced with use of rainwater)

3) Recycling:

a) Greywater: Max. Use For Summer Lawn Watering

b) Household Waste Storage: 30 litre (metal, plastic, compost, glass)

c) Outdoor Compost Bin: 630 litre

d) Maximum Use of Natural and Renewable Materials.

4) Maximum Carbon Dioxide Emissions: 40 kg per sq.m. per year

5) Most Construction Waste to be Recycled ie. Placed in Wall Cavities

D. Electrical:

1)	Refrigerator:		<0.05 kWh per month per litre
2)	Stove:		<65 kWh per month or <0.25 GJ per month
3)	Clothes Washer:		<55 kWh per month
4)	Clothes Dryer:	a) Primary Source:	Manual
		b) Secondary Source:	<95 kWh per month or <0.33 GJ per month
5)	Dishwasher:	a) Primary Source:	Manual
		b) Secondary Source:	<85 kWh per month or 0.36 GJ per month
		c) Water Consumption:	<35 litres per cycle
6)	Other Energy Appliances to be in top 10 percent performance according to Energuide.		
7)	Lighting:	a) Per Area:	<8 watts per sq.m
		b) Average Lighting Output:	Minimum 40 lumens per watt
8)	Photovoltaics:	a) Minimum Production:	600 kWh per year
9)	Fan Energy:	a) Max. Power Consumption:	1.2 watts per litre per second
10)	Max. Electrical Equipment Power Consumption:		4000 kWh per year

E. Indoor Environment (Exposure Guidelines):

1)	Aldehydes:	a) Formaldehyde:	0.05 ppm from carpets, curtains, furnishings
		b) Acrolein:	0.02 ppm
		c) Acetaldehyde:	5.00 ppm
2)	Carbon Dioxide:		<3500 ppm
3)	Carbon Monoxide:		<11 ppm
4)	Nitrogen Dioxide:		<0.25 ppm
5)	Ozone:		<0.12 ppm from electric motors

6) Particulate Matter:		40 ug/cubic meter from smoke, dust
7) Sulphur Dioxide:		<0.38 ppm
8) Radon:		2pCi/l
9) Electromagnetic Pollution:		2 mG maximum at 0.610m (2 ft.)
10) Thermal Comfort:	a) Temperature:	15-22 deg. C (18 deg. C Avg.)
	b) Relative Humidity:	30-60%
	c) Maximum Temperature Swing:	5 deg. C
11) Noise Criteria:		<25 NC

Legend

ppm = parts per million

ug/cubic meter = micrograms per cubic meter

pCi/l = picoCuries per litre

These performance guidelines are typically used to monitor energy efficiency features and also basic environmental qualities in and outside the home. The sustainable house has been designed and specified according to these performance standards. The result will be evaluated in terms of both energy and monetary savings.

APPENDIX 3

A Photovoltaic and Grid-Connected Electrical System

Prepared by

Ian Moir

1. INTRODUCTION

The objective of this report is to present some of the alternatives for the electrical system of the Generic Sustainable House being designed by A.C.E. - Alternative and Conservation Energies Inc. The house is designed to reduce environmental impact and degradation, in a cost effective and marketable manner. It is hoped that the project will also provide a means of rethinking how housing is designed and built. The greatest energy expenditure in the life cycle of a house is the energy needed for day to day operation. Most of that energy in Canada goes for space and water heating.

The subject of this report will be the other component of day to day energy use, electrical power. Since electricity is not generally used for heating in Alberta, this will not be directly discussed in this document. The Sustainable House is not only designed to reduce electrical energy consumption, but to generate some of that energy using renewable sources where possible. The house at this point is designed to incorporate 10 photovoltaic modules. Other sources could be added as appropriate. This report will also discuss the reduction of power consumption by using efficient appliances and eliminating unnecessary loads.

There are a few general issues to keep in mind regarding the design of the electrical supply and appliance system. The first issue is that the seasonal use of an appliance is important when using photovoltaics to generate electrical power. It makes little sense to use photovoltaics to power an appliance that uses little power in summer and uses more power in winter. Ideally, one would connect a high summer load and low winter load to a photovoltaic system, such as air-conditioning and possibly refrigeration.

2. ELECTRICAL POWER SYSTEM CONFIGURATIONS

Many electrical configurations are possible for the sustainable house. The one used depends on the particular circumstances of each project. For an off grid house using very low amounts of electrical energy, the entire house would be wired for 12VDC operation whereas an urban house with shading problems, ie. no photovoltaics, may simply be wired for conventional 120VAC. Many different sources of electrical power can be used by the sustainable house. Renewable sources include photovoltaics, wind generation and micro-hydro. Backup sources can be diesel or gasoline generators or the grid system.

The two basic house wiring configurations discussed are 120VAC and low voltage DC. Many appliances are available to run on 12VDC. Some are also available in the 24VDC variety. Some of the advantages and disadvantages of a low voltage DC system over 120VAC are as follows:

Advantages:

- Ease of adapting to battery storage systems
- More efficient when using battery storage systems
- No need for expensive and possibly inefficient inverters
- Possibly less electro-magnetic fields (EMF) from wiring system
- Less susceptibility to electric shocks
- More efficient for appliances that are DC in nature

Disadvantages:

- Less choice in terms of appliances
- More resistive losses in wiring offset by thicker (more expensive) gauge of wire.
- Uncommon standard
- Need specialized electrician

Battery storage systems are important to wind, photovoltaic and, to a lesser extent, micro-hydro power generation systems. In the case of photovoltaic and wind systems, batteries are usually used to store energy for use during low light situations or when the wind doesn't blow. In a micro-hydro situation, batteries can be used to level the generation of power from a varying load. Battery storage systems are also useful in rural areas as emergency backup during power blackouts.

The three main power system configurations considered for the sustainable house are: all DC; all AC; or a combination of AC and DC. The following sections all assume that some kind of renewable energy generation system is being used.

2.1. OPTION ONE: DC only power supply system

This is probably the system of choice for die-hard power conservers and low power users. This is easier to use, requires less equipment to install and is more efficient when using batteries for storage. The main disadvantage is the power/wire gauge trade off. A 10 amp circuit will be able to supply 1200 watts at 120VAC, but only 120 watts at 12V. At 12V, this circuit is likely enough to power one bedroom only if power use is efficient and limited. The bedroom circuit would likely be limited to one main fluorescent light, one or two efficient reading lights, an electric alarm clock, and a low power sound system. For higher power circuits, higher gauge wire would have to be used. Moderate power appliances (>150 watts, <1500 watts) such as hairdryers, toasters, fridges, microwave ovens and televisions would all need higher gauge circuits. High power appliances (>1500 watts) such as electric clothes dryers, electric ranges and electric hot water heaters should be avoided. These loads are not appropriate to photovoltaic battery storage systems, but may be more appropriate to solar thermal.

This configuration should only be used if the decrease in convenience is acceptable, in an off grid situation where batteries are used to store power. Part of the decrease in convenience has to do with less choice of appliances. There is also likely to be less power capability that will be available from each circuit, and therefore less appliances can be used per circuit. One solution to these problems is to learn to use fewer appliances and ultimately, less electricity.

In a DC only supply system, batteries will likely be used to store electrical energy for situations when alternate generation is not available, ie. nighttime for photovoltaics. When over a period of time, alternate generation is not available in sufficient quantity to charge the batteries, ie. photovoltaics during winter, a backup system must be used. If the backup is a genset (diesel or gasoline powered generator), the generator would be switched on to either charge the batteries or even just to supply a particularly large load. If the backup is the grid, the grid power would be converted to power the house but not to charge up the batteries. This is because there are inefficiencies in charging batteries that are eliminated by using power directly from the AC-DC converter. Batteries also have to be changed after so many discharge and recharge cycles. These inefficiencies and costs are offset in the genset case by the improvement in generator life and efficiency by running it only at its rated power for short periods of time.

2.2. OPTION TWO: AC only power supply system

This configuration should be used when connected to the grid and no other power sources are used. If alternative power sources are used to supplement grid power, a few scenarios are possible. There are two basic types of AC power supply systems, one where the alternate power system synchronizes to the cycles of the grid power system, and one which doesn't.

2.2.1. Synchronous interconnection of power supplies

A synchronous system can be used to interconnect the grid and other power sources. In this kind of system, the other power sources would synchronize their generators to the 120VAC cycles of the grid. This system has the advantage of not requiring storage devices thus saving money on batteries and possibly inverters. When power generation exceeds consumption, excess power can be sold to the power utility.

There are some disadvantages to supplying power to a utility grid. Connecting to the grid is not an easy process. It requires a utility willing to explore and work with interested parties to make this kind of connection a success. Stringent standards must be maintained so as to not "disturb" the stability and quality of the grid power. This may require expensive and complicated monitoring equipment. Small wind generators and micro-hydro generators, being mechanical in nature, could theoretically easily be built using synchronous generators. However, these are not widely available.

DC generating sources such as all photovoltaics and most wind and micro-hydro generators would have to be connected to the grid through a synchronous inverter. These are expensive, uncommon and the efficiency is unknown. Research is needed to find out what kind of equipment is available.

2.2.2. Asynchronous interconnection of power supplies

In this kind of system, there are two supply subsystems, one powered by a set of storage batteries using an approximate sine wave inverter to convert the DC power to 120VAC. The second supply subsystem is the backup system, either the grid or a generator.

There are two potential problems to this kind of system. Since these two subsystems are not synchronous, when the batteries become discharged, the power supply circuit must be switched from one circuit to the other. This will generally cause a discontinuity in the cycles and levels of the AC supply for a short time, which may affect the operation and even damage some appliances such as digital clocks, computers, VCRs, AC motors and others. One way to get around this is to get the backup system to feed into the battery system. This would have the effect of converting 120VAC from the grid or generator to 12VDC, charging the batteries, and then reconverting the power from DC to AC with all of the inefficiencies involved.

The second problem with this system is that while the cost of the modified sine wave inverter is a fraction of the price of a synchronous inverter, they do not produce a real sine wave, and they are not CSA approved. In many places, such as Alberta, it is difficult to get inspectors to accept the general use of such inverters.

2.3. OPTION THREE: AC/DC combination wiring system

A combination wiring system may be designed to combine the advantages of each of the above systems. DC circuits could be used where the loss of convenience can be tolerated such as in bedrooms or storage areas or for permanently and semi-permanently connected appliances such as lighting fixtures, refrigeration, fans, ventilators and others. In the case of these fixed appliances, the load on the circuit is known so that oversizing the circuit is less critical and the circuit does not become so expensive. The rest of the house can then be wired to the power grid's 120VAC.

The alternate sources of energy could then be used to charge batteries that would supply only the DC circuits. When not enough power is produced by the alternate sources, the AC backup would be used to supply the DC circuits. The load could be designed so that little power is wasted when the alternate sources are in full generation, and then use the backup efficiently the rest of the time.

An advantage of this system is that inverters and all their problems, efficiency losses and expense are done away with. Also, appliances that are more appropriately served by DC power can easily be connected up to a DC source. This system is ideal for a grid connected backup, but can still be used for a generator backup system. Then, batteries are used to power an inverter, as well as the DC circuits.

2.4. Recommendations

The Sustainable House electrical power system configuration should either be the AC only synchronous grid connected system or the AC/DC combination system. Two recommendations are made. The synchronous system is seen as a demonstration system where as the AC/DC is seen as an efficient system for common use.

2.4.1. Synchronous Grid Connected System

The grid connected system should be adopted since it would be an innovative use of photovoltaics in Alberta. This would be a good demonstration system to increase public awareness. There are no grid connected photovoltaics in Alberta. The sustainable house could spearhead the connection of very small power producers to the grid. With the support and participation of the utilities, a great deal could be learned from connecting such a source to the grid. Information such as efficiency, availability, reliability and cost, is needed on the equipment required to connect a small power source to the grid.

2.4.2. AC/DC Combination System

The AC/DC combination system is an efficient system that combines the advantages of DC and AC systems. This kind of system would be particularly well suited to photovoltaics if the seasonal variation of the load could be matched to the seasonal variation of the photovoltaic power output. The ideal loads for this system would be loads that increase in the summer, and decrease in the winter.

3. APPLIANCES

The following sections include information on energy saving appliances by category.

3.1. Lighting

By far, fluorescent lighting is the most efficient lighting available. With the development of electronic ballast, the traditional problems of delays turning the bulbs on, humming and flickering have nearly been eliminated. The light color has also been improving with the development of a variety of tube coatings. Screw-in replacements for traditional incandescent bulbs are increasingly available. Fluorescent bulbs should not be used outside since they may not work in cold weather. Fluorescent fixtures are much more expensive than incandescent fixtures, but because they last much longer and use less power, they are usually cheaper to use over the lifetime of the equipment. Fluorescent bulbs will typically last on average up to 10,000 hours compared to most incandescent bulbs which last only about 1000 hours.

Traditional core-coil ballast long tube fluorescent 120VAC fixtures are widely available. Electronic ballasts are more expensive and difficult to find. Compact fluorescent bulbs which screw into the traditional "Edison" socket are getting easier to find by the day. 12VDC fixtures are also more expensive and are still somewhat difficult to find.

Halogen light bulbs are about 50% more efficient, last twice as long and are more expensive than normal incandescent light bulbs. They also produce a high quality white light that is very suitable to spot lighting since the bulbs are very small. A 20W bulb can make a much better light source for reading than a normal 60W incandescent, and save one third the power. Halogen bulbs are also only available for 12V so that transformers are needed when used from a 120VAC circuit. When a transformer is used it is important to understand that turning the light off may not cut the transformer from the live circuit so that a small amount of power will always be used. This is remedied by turning the power off to the transformer.

As inefficient as conventional incandescent lighting is, there are situations where it is the best option. It makes little sense to spend $20 for a light bulb in a storage area which will only be used a few hours a month when a one dollar bulb will do the same thing, using just pennies more power.

Task lighting should be used where possible. This is when a light is designated for a particular task, such as reading in bed, so that the general lighting for the room can be of a lower intensity. This can be used for reading, kitchen counters, laundry counter and any other work area.

The seasonal load due to lighting generally increases during winter as lighting is needed both in the morning and evening during the long hours of darkness. When it gets cold and dark outside, household members will also spend more time in the house increasing appliance use in general, lighting in particular.

Another lighting issue is that of full spectrum lighting. This is believed by many to be very beneficial to humans, particularly those who live in northern climates who do not have much exposure to sunlight during the winter time. Normal lighting does not provide much ultraviolet light. Some bulbs have been developed to provide light from the ultraviolet spectrum. They do not seem to be very consistent and the ultraviolet part of the spectrum seems to fade away early in the lighting lifetime of the bulb.

3.2. Refrigeration

Many options are available for refrigeration. Some of the most efficient fridges are available in either 12VDC, 24VDC or 120VAC (Sun Frost and Photocomm). These tend to be very expensive and usually not readily available. The Sun Frost fridges, which are by far the most efficient, use about one fifth the energy of a conventional fridge but are handmade and four or five times the price. The Photocomm fridge is about three times the price of a conventional fridge and uses about one third the energy. There is also a potential problem with the maintenance and repairs of these units since they are not manufactured or widely distributed in Canada.

Some more commonly available fridges are quite energy efficient. W.C. Wood's fridges (manufactured in Guelph Ontario) are probably the most efficient that are widely available in Canada. The main disadvantage is that they are fridges only, with no freezer section. However Wood's 17.4 cu.ft. fridge and 12 cu.ft. chest freezer use about as much power as the average large fridge/freezer combination (about 18-20 cu.ft. total). The following table shows information on several fridges. Note that manual defrost fridges are the most efficient.

Manufacturer[1] defrost Auto or Manual	Power W/day	Volume Refrigerate/ Freeze/Total cu.ft.	12V or 24V DC available[3]	Retail Price
Sun Frost M	540	10.3 / 4.0 / 16.0[2]	Yes	$2560US+shipping
Photocomm M	800	11.5 / 4.5 / 16.0	Yes	$1995US+shipping
Wood's (fridge) A	1200	16.4 / 0.3 / 16.7	No	
Wood's (freezer) M	1270	00.0 / 9.0 / 9.0	No	
Wood's (total)	2460	16.4 / 9.3 / 25.7	No	
Admiral A	2500	12.5 / 4.0 / 16.5		
Amana A	2430	13.3 / 4.5 / 17.8		
Beaumark A	2830	12.5 / 4.3 / 16.8		
Caloric A	2700	12.3 / 3.9 / 16.3		
Frigidaire M	1500	12.7 / 1.7 / 14.4		
Frigidaire A	2500	10.3 / 3.3 / 13.6		
General Electric A	2400	13.1 / 5.1 / 18.2		
Hotpoint A	2400	12.7 / 5.0 / 17.7		
Inglis A	2500	11.0 / 3.6 / 14.6		
Jenn-Air A	2500	10.4 / 4.2 / 14.6		

1 Data for all appliances except Sun Frost and Photocomm taken from Energy Mines and Resources Energuide Directory of 1989. For each manufacturer, the most efficient fridge close to 16 cu. ft. was used.

2 Sun Frost brochure explains that by government measuring standards, it is a 10 cu. ft. fridge, but not all of this is usable. This is why the numbers don't add up.

3 Energuide does not indicate whether appliances are available for DC operation, although it is probable that they are not. Wood's brochures seem to indicate 120V 60cycle operation only.

The refrigeration load is a significant one, accounting for about 25% of the average household load. Reducing it would have an important effect on the overall energy consumption of the home. There is also much room for innovation in the use of fridges. Sun Frost has developed an outside fin that attaches to its fridge. The fin would be mounted on the outside of the house and when the temperature is low enough, the fridge is passively cooled. This not only reduces the electrical load, but does so during the coldest months of the year, when the production of electricity from photovoltaics is at a minimum. The outside fin system is no longer available with Sun Frost fridges.

The outside fin system developed by Sun Frost is not ideal though. It only works for the fridge section so it will only reduce the energy consumption by a maximum of about 33%. Also, when it is too cold outside, there is the danger that the fridge section will freeze. At this point, the fin system must be shut off, and electrical power used to cool the fridge. This is an entirely passive system and there are no automatic controls. The user must track the outdoor temperature and manually shut off the fin when it gets too cold.

This is somewhat inconvenient and will likely lead to some spoiled food. Better use of outside cold should be explored to reduce the refrigeration load in a convenient and automatic manner. This would be ideal for photovoltaic systems in Canada. Cold water intake used for the toilet or for hot water could also be used to cool the refrigerant to make the fridge more efficient.

3.3. Entertainment

A wide variety of entertainment components are available that can accommodate either 120VAC, 12VDC or both. Some work should be done to find the most efficient ones.

Color televisions are probably the largest power consumers in the entertainment area. They use about six times the power of black and white TVs. A radio can be a very low power consumer, with cassette tape players, record players and CD players all using a bit more power. Some popular average sized "Ghetto Blasters" are rated for about 14 watts. A smaller radio cassette tape player combination would be about four watts.

Colour televisions are typically rated for 200 watts. 12VDC televisions are available from a US mail order catalogue which use from 12 watts for the black and white model to 66 watts for a colour model. There is also a video cassette player (VCP) that uses 9.6 watts and a colour TV/VCP combination that uses 66 watts when both are running.

Satellite dishes would be particularly useful for someone who does not want to do without a TV but is too far from cable or transmitters to get the service desired. More research has to be done on these.

3.4. Ventilation

An important load in the sustainable house will be the Heat Recovery Ventilator (HRV). Since the house will be air tight, fresh air will have to be vented in, and stale air vented out. The HRV is used to recover as much of the heat from the outgoing air as possible. HRV use is most intense in winter for two reasons. One is that circulation of fresh air depends on the HRV since the house will be well sealed and windows will be kept shut. Also, the HRV will dehumidify the house, removing excess humidity, especially from the bathrooms and kitchen. The removal of frost from the HRV as stale warm humid air is cooled to below the freezing point requires large amounts of power, similar to frost-free cycles in frost-free refrigerator/freezers. HRV use in summer would likely be minimal.

The ceiling fan is used year round but particularly during the coldest and warmest days. During winter, it is used to help destratify the air, as warm air will tend to collect near the ceiling and cold air near the floor. During hot summer days, the air movement induced by the ceiling fan can dramatically increase the comfort level by creating air movement downward or assisting the evacuation of warm air out of upper windows. This may allow for a higher temperature setting of the air conditioner if one is used. Ceiling fans are widely available for 120VAC. A 12VDC model is available from a US mail order catalogue which uses six to nine watts.

The destratification fan is used during heating days in the house to take stratified warm air in the "ceiling" of the house and circulate it in the concrete slab flooring. Its use in summer would be minimal while winter use would greatly be increased. Efficient DC or AC fans can easily be found.

Air conditioning is an extremely high load and should be managed carefully. It should only be used if really needed and when other cooling or comfort systems, such as window shading, passive cooling, thermal mass and ceiling fans, have been used and are insufficient. A dehumidifier may be a more appropriate and cost effective solution to comfort and humidity problems in muggy weather prone areas. In Alberta, neither appliance is generally needed. Fortunately though, these loads are highest during the hottest days of summer, which tend to be sunny days when photovoltaics are generating much power.

3.5. Kitchen Appliances

Toasters are popular medium power appliances typically rated at 700W of power for a two slice toaster. In a 12VDC system, they would require a very high amperage, about 60 Amps. A DC toaster, if one could be found, would likely need its own circuit.

Microwave ovens require quite a bit of power, but when compared to a conventional oven, they are quite efficient since most of the power goes into heating the food. Microwave ovens are typically rated for 1200 watts. An electric oven typically requires about 1000 watts, and takes much longer to heat food. In a 12VDC system, the expense of a special circuit for the microwave may well be worth while. A source of DC microwave ovens should be found. Some people are concerned that microwave ovens pose a health risk to humans; that microwaves escaping the unit can be harmful. There is also concern that the microwaves may adversely affect the food itself.

Boiling water using a kettle is more energy efficient that using a stove element. 12VDC models have not been located. However, a US mail order catalogue has a 12V beverage heater. This is a probe which is inserted in the liquid and warms it up. It uses 96 watts.

Other electrical kitchen appliances such as electric can openers should be avoided as they are unnecessary.

Most cooking functions are more appropriately served from both an energy efficiency and environmental perspective by sealed combustion gas ranges.

3.6. Office

Personal computers can use large amounts of power. The general rule of thumb is the more powerful a computer, the more power it needs. Computers should be sized to their intended use. Portable computers running off batteries are probably the most efficient since manufacturers have devised many power saving features for these.

Many traditional phones do not require any power additional to that of the phone circuit. These phones should be used when the added features of a non phone circuit powered phone are not really needed. A 12VDC phone and answering machine with all the features which uses 2.4 watts is available from a US mail order catalogue. Another answering machine uses only 1.2 watts.

3.7. Others

Circulating pumps are used to circulate warm liquid in the concrete slab floor to heat the house. Most of the load would be during winter.

Clothes washers are another large power user, and they also use large amounts of water. A 12VDC washer which uses 66 watts is available from a US mail order catalogue. However, this is not the large fully automatic cycle washer that we have become accustomed to.

Clothes dryers typically use about four to six kilowatts of power. This is a very heavy load and should be avoided if possible. They also vent heated air to the outside increasing the space heating load. Clothes lines should be used, outside in the summer and inside assisted with fans in the winter.

Dish washers are another luxury that should be avoided in an energy efficient house. They require very hot water and use much electrical power during the drying cycle. A wash and dry cycle typically uses 1.5 kilowatt hours of electrical energy; this does not include the energy required to heat the water.

Hair dryers generally are on the high side of the moderate power consumers. They are typically rated for about 1200 watts. A 12VDC hairdryer is available from a US mail order catalogue which uses 144 watts.

Vacuum cleaners are not really needed in the sustainable house. No wall to wall carpets will be installed, so hard floors can be swept and washed, and sweepers can be used on rugs. A typical vacuum cleaner with power nozzle is rated at about 1000 watts. 12VDC carpet oriented vacuum cleaners available from a US mail order catalogue use rechargeable batteries. This eliminates the problem of line losses in the power chord. The catalogue also has a 12VDC canister vacuum cleaner, but no power rating is given.

Clock radios have become very popular. The clock part of the radio typically uses only a few watts of power. While this is not very much, windup clocks do not use any power and should be considered. Another associated problem of the clock radio is that some emit large amounts of electro-magnetic radiation. This is of concern since we spend much of our lives quietly sleeping near our clock radios. These may be one of the largest sources of EMF in our lives.

Smart technology can be used to control appliances from a central location. This will be explored as specific understanding of the total appliance load is understood.

3.8. Recommendations

Only a few general recommendations will be summarized here. The above sections contain information that individuals can use to make choices.

As much of the lighting as possible should use fluorescent technology. Because of their efficiency, microwave ovens should be used.

Clothes dryers and dishwasher should be avoided due to their large power consumption.

It is also recommended that one of the efficient fridges is used. While the Sun Frost fridge is extremely energy efficient, it is very expensive. The Photocomm fridge is likely more appropriate and a good choice, but is still about three times the price of a conventional fridge. Research should be done to see whether convenient refrigerators can be built to take advantage of the cold Canadian winter to reduce the refrigeration load. This would be a particular advantage to a combination AC/DC power system since the refrigeration load would follow the DC power generation profile of photovoltaics.

The use of smart technology to control and mitigate electrical power use should be explored.

4. RENEWABLE SOURCES OF POWER

4.1. Photovoltaics

Photovoltaic cells convert light directly into electricity. Cells are made from semiconductor materials, commonly silicon. Cells are grouped together on a panel to make modules. A module's power rating is the power an average module will generate in full sunlight (a radiation power of 1000 watts/m^2 at 25°C). Several modules can be combined into an array.

It is difficult to collect the rated power from a module. The peak power point voltage and current vary with light intensity and temperature. As light intensity drops, peak power current drops and as temperature rises, peak power voltage drops. Battery chargers and inverters generally operate at a given voltage and cannot track the peak power point. A significant amount of potential power is lost due to this. Techniques for tracking and using peak power should be investigated.

Another power reducing phenomenon is that modules of the same power rating will behave slightly differently. This is a slight problem because when several modules are placed together in an array, they may perform to the worst performing module in the array. This can be minimized by matching modules and using certain array configurations. In a small array, this is not a big concern.

Photovoltaics are relatively inefficient since they only convert about 10 to 15 percent of radiation energy to electrical energy. They are also expensive making the initial cost of installation high, but once installed are extremely reliable and will produce free power for upwards of 30 years.

When planning the installation, it is extremely important that no part of the array will be obstructed from the sun at any time, during any season. Shading on any part of a module may significantly reduce the performance of the module and possibly the entire array depending on the configuration. Even the shadow of a cable crossing the array must be avoided. This may be a problem in urban areas with utility wires and poles,growing trees, and neighbors erecting obstructions.

Some loads are highest during the hot days of summer, when the power output from arrays is highest due to good availability of sunlight. During the design of arrays, it must be remembered though that power generation can decrease as temperature increases. This problem can be avoided in a well designed system where the degradation in performance is taken into consideration.

Photovoltaics can also be used to generate the power needed during the construction of the sustainable house. The photovoltaic array can be set up on a temporary basis and used by power tools. Many power tools now use batteries so that photovoltaics can be used to keep the batteries charged.

4.2. Wind generators

In any area where there is sufficient wind, a wind generator should be considered. They are usually much more cost effective than photovoltaics. However, they are mechanical in nature, less reliable and would require more maintenance.

4.3. Micro hydro

Micro hydro is the term used to denote systems which collect power from falling or moving water in a relatively non-intrusive fashion. Water that can be piped from a higher elevation to a lower elevation can easily be used to generate electricity. These systems tend to supply electrical power at continuous levels, unlike wind or photovoltaics. Generally, they are more cost effective than photovoltaics and wind, but also suffer from moving parts and higher maintenance. Winter ice and lower volumes of water are two other specific problems associated with micro-hydro.

4.4. Other

A US mail order catalogue includes a Cycle Generator. This hooks up to a bicycle and can generate about 100 watts from a good cyclist. You probably don't want to power your house this way but if you are using an exercise bike anyway, you might as well use this. And as the catalogue points out, this is a great way to encourage the kids to limit their TV watching: no TV unless you generate the power for it.

5. CONCLUSIONS

Two interesting power configuration options have been identified: a grid connected photovoltaic array; and a combination AC/DC supply and wiring system. While the grid connected system is innovative, the combination system is efficient and economical. The combination system would be even more attractive if a fridge could be developed that used cool weather to lessen the refrigeration load.

Many choices can be made to reduce the electrical load. Some appliances such as vacuum cleaners, clothes dryers and dishwashers should not be used. For appliances such as fridges, some very efficient models should be used.

APPENDIX 4

Comparative Inventory Chart

COMPARATIVE INVENTORY CHART

Legend

● GOOD ◍ AVERAGE ○ POOR

/ NOT APPLICABLE ? QUESTIONABLE Y - YES N - NO

CRITERIA	Practicality	Marketability	Cost-Effective	Durability	Local Manufacture	Availability	Indoor Air Quality	Environ. Impact	Conservation	Recyclability	Embodied Energy	Simplicity	Do-It-Yourself	Low Maintenance	Renew. Resource	Energy Consump.	CO_2 Emmissions		INCLUDED	CONVENTIONAL (NON-R-2000) HOUSE	INCLUDED
FEATURES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17				
HEATING/COOLING																					
a) Greenhouse	●	◍	○	●	●	●	●	●	●	●	◍	●	●	○	●	◍	●		Y		N
b) Solarium	●	●	◍	●	●	●	◍	●	●	/	●	●	●	◍	●	◍	●		/		N
c) Passive Solar	●	◍	●	/	●	●	●	●	●	●	●	●	●	◍	●	●	●		Y		N
d) Air-to-Air Heat Exchanger	◍	○	○	◍	○	○	●	○	○	○	○	○	◍	◍	○	○	○		Y		N
e) Thermal Mass (ie. sand)	○	○	○	●	●	●	●	○	/	●	●	●	◍	●	●	●	●		N		N
f) Passive Cooling	●	○	●	●	○	●	●	●	●	/	/	●	●	●	●	●	●		Y		N
g) Active Solar Heating	○	○	○	◍	○	○	/	◍	●	◍	◍	○	◍	○	●	●	●		N		N
h) Hybrid (ie. large fan)	●	●	○	●	○	●	●	/	●	○	○	●	◍	●	◍	○	●		Y		N
i) Venetian Blinds	●	●	◍	●	○	●	/	/	/	●	○	●	●	◍	●	●	●		Y		N
j) Radiant Floor Heating	○	●	◍	◍	●	●	●	/	●	○	○	●	●	●	○	◍	○		Y		N
WATER																					
a) Breadbox Solar Preheater	●	◍	●	●	●	●	◍	●	●	●	◍	●	●	●	●	●	●		Y		N
b) Waste Water Heat Exchanger	○	○	?	●	○	○	/	●	●	●	●	◍	◍	○	●	●	●		N		N
c) Water Conservation	●	◍	●	●	○	◍	/	●	●	/	/	●	●	●	/	●	/		Y		N
d) Water Meters	●	◍	●	○	?	●	/	●	●	○	○	●	○	●	?	●	/		Y		YN
e) Waste Water Recycling	●	○	●	/	●	●	/	●	●	●	●	●	●	○	●	●	/		Y		N
f) Low Flush Toilet	●	●	●	●	○	○	/	●	●	/	◍	●	○	●	/	●	/		Y		N
g) Waterless Toilet	○	○	○	●	○	○	○	●	●	●	●	●	○	○	●	●	●		N		N
h) Rain Water Collectors	◍	◍	●	●	◍	●	/	●	●	●	●	●	◍	◍	◍	●	●		Y		N
ELECTRICITY																					
a) Maximum Daylighting	●	●	○	●	●	●	/	●	●	/	●	●	●	●	●	●	●		Y		N
b) Photovoltaics	○	○	○	●	○	○	/	●	●	◍	●	●	●	●	●	●	●		Y		N
c) Gas Clothes Dryer	●	●	●	●	◍	●	○	○	○	/	○	●	●	?	○	◍	○		N		N
FEATURES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17				

																				CONVENTIONAL (NON-R-2000) HOUSE
ELECTRICITY																				
d) Energy Efficient Appliances	●	●	●	●	○	◍	/	●	●	○	◍	●	/	◍	●	●	●		Y	N
e) Smart Technology	◍	●	○	/	○	◍	/	●	●	○	/	●	●	●	●	●	●		N	N
f) Energy Efficient Lighting	●	●	●	●	○	◍	/	●	●	◍	○	◍	●	●	●	●	●		Y	N
CONSERVATION																				
a) Higher Levels of Insulation	●	●	●	●	●	●	●	●	●	●	◍	●	●	●	●	●	/		Y	N
b) Air-Tight Construction	●	◍	○	◍	/	/	●	/	●	/	/	◍	◍	◍	●	●	●		Y	N
c) Weather Stripping & Caulking	●	●	●	●	●	●	●	●	●	/	/	●	●	◍	●	●	◍		Y	Y
d) High Performance Windows	●	●	○	◍	◍	◍	/	●	●	/	◍	○	/	◍	●	●	◍		Y	N
e) Small N, E, W Windows	●	●	●	/	/	/	/	●	●	◍	◍	/	/	◍	●	●	/		Y	N
f) Airlocks / Mudrooms	●	●	●	/	/	/	●	●	●	/	/	●	●	●	○	○	/		Y	N
g) Energy / Water Cost Indicator	●	●	◍	/	○	○	/	●	●	/	/	●	○	○	○	○	/		N	N
h) Set-Back Thermostats	●	●	●	●	◍	◍	●	●	●	/	/	●	●	○	○	○	/		Y	N
i) Built-In Recycling Containers	●	●	●	●	/	/	/	●	●	●	/	●	●	●	○	○	/		Y	N
j) Less Use of Depleting Sources	●	●	●	/	/	/	/	●	●	/	/	○	○	○	●	●	●		Y	N
k) Energy Conserving Landscaping	●	●	○	◍	/	◍	/	●	●	●	/	◍	◍	◍	/	/	●		Y	N
l) Garden Compost Pile	◍	◍	◍	/	/	/	/	◍	●	●	/	●	●	○	◍	/	/		Y	N
m) Organic Garden	◍	◍	◍	○	/	/	/	●	●	◍	/	◍	●	◍	/	/	/		Y	N
ARCHITECTURAL																				
a) Low Maintenance Materials	●	●	●	●	●	●	◍	●	◍	○	○	◍	◍	●	◍	◍	◍		Y	Y
b) Pre-Fabricated Houses	◍	○	◍	●	●	○	/	●	●	●	◍	◍	/	/	/	●	●		N	N
c) Slab on Grade Construction	●	○	◍	●	●	●	●	●	●	/	○	◍	○	◍	●	●	/		Y	N
d) Shallow Footings	●	◍	●	●	●	●	/	●	●	/	/	◍	○	●	●	●	●		Y	N
e) No Basement	◍	○	●	/	/	/	●	●	●	/	/	●	/	/	/	/	/		Y	N
f) Smaller House	◍	◍	●	/	/	/	/	●	●	/	/	●	/	/	/	●	●		Y	N
g) Open Plan	●	●	●	/	/	/	●	●	●	/	●	●	/	/	/	●	○		Y	N
h) Multi-Purpose Rooms	●	◍	●	/	/	/	●	●	●	/	/	●	/	/	/	●	○		Y	Y
i) Porch	◍	◍	○	◍	/	/	/	/	/	/	/	◍	◍	◍	/	/	/		N	N
j) Car Port vs. Garage	●	◍	●	/	/	/	/	○	●	/	/	●	◍	◍	/	/	/		Y	N
FEATURES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
ARCHITECTURAL																				
k) Cold Storage Room	●	●	●	●	/	/	/	◍	●	/	/	●	◍	/	/	/	/		Y	N

l) No Fireplace	●	○	◍	/	/	/	●	●	●	/	/	/	/	/	●	/	●		Y	N
m) Livable Attic	●	◍	●	/	/	/	◍	●	●	/	/	◍	/	/	/	/	/		Y	N
n) Home Office	●	●	◍	/	/	/	/	/	/	/	/	◍	◍	/	/	/	/		Y	N
o) Rental Suite	◍	●	○	/	/	/	/	/	/	/	/	◍	◍	/	/	/	/		N	N
p) Local Materials vs. Imported	●	●	●	◍	◍	◍	/	●	●	/	●	/	/	/	◍	◍	◍		Y	N
q) Do-it-yourself Features	◍	○	●	/	/	/	/	/	/	◍	/	◍	●	/	/	/	/		Y	N
OTHER																				
a) Air Pollution Monitor	●	◍	○	?	?	○	●	●	○	/	/	◍	◍	?	/	/	●		N	N
b) Low Indoor Air Pollution	●	●	/	/	/	/	●	●	●	/	/	/	/	/	/	/	/		Y	N
c) Air & Water Filtration	●	●	?	◍	○	○	●	◍	◍	/	/	◍	◍		/	/	/		N	N
d) Smaller Lots	●	○	◍	/	/	/	/	●	●	/	/	/	/	/	/	/	/		N	N
e) Place Heating Appliance Outdoors	●	◍	○	◍	◍	◍	●	●	●	/	/	/	/	○	/	◍	●		N	N
f) Self Sufficiency	◍	○	◍	?	/	/	/	●	●	/	/	○	◍	?	●	●	●		N	N

CONVENTIONAL (NON-R-2000) HOUSE